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THESIS

STRUCTURAL DESIGN ANALYSIS OF THE TAIL LANDING GEAR BAY AND THE VERTICAL/HORIZONTAL STABILIZERS OF THE RAH-66 COMANCHE HELICOPTER

by

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September, 1997

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The RAH-66 Comanche's stealth design requires the use of radar-absorbing material (RAM) on the outer skin of the aircraft. The reduced stiffness properties of RAM produce insufficient tail torsional stiffness, necessitating the use of non-radar-absorbing graphite on the outer skin of the prototype's tail section. This thesis investigates structural design modifications to increase the tail section's stiffness to allow the use of RAM on the outer skin and still meet all structural requirements. An original model represents the prototype aircraft at first flight. The goal is to create a model using RAM on the outer skin that matches the structural stiffness of the original model. This thesis builds on earlier work conducted at the Naval Postgraduate School (NPS). Two new design modifications to the tailcone are developed. The best modification increases the torsional stiffness of a baseline model by six percent. Integrating earlier NPS modifications increases torsional stiffness by 12 percent. When RAM is applied to the outer skin of the modified model, torsional stiffness is reduced by only six percent from the baseline as compared to a 24 percent reduction with no modifications. Additional modifications to the vertical and horizontal stabilizers further increase structural stiffness and reduce weight.

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STRUCTURAL DESIGN ANALYSIS OF THE TAIL LANDING GEAR BAY AND THE VERTICAL/HORIZONTAL STABILIZERS OF THE RAH-66 COMANCHE HELICOPTER

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ABSTRACT

The RAH-66 Comanche's stealth design requires the use of radar-absorbing material (RAM) on the outer skin of the aircraft. The reduced stiffness properties of RAM produce insufficient tail torsional stiffness, necessitating the use of non-radar-absorbing graphite on the outer skin of the prototype's tail section. This thesis investigates structural design modifications to increase the tail section's stiffness to allow the use of RAM on the outer skin and still meet all structural requirements. An original model represents the prototype aircraft at first flight. The goal is to create a model using RAM on the outer skin that matches the structural stiffness of the original model. This thesis builds on earlier work conducted at the Naval Postgraduate School (NPS). Two new design modifications to the tailcone are developed. The best modification increases the torsional stiffness of a baseline model by six percent. Integrating earlier NPS modifications increases torsional stiffness by 12 percent. When RAM is applied to the outer skin of the modified model, torsional stiffness is reduced by only six percent from the baseline as compared to a 24 percent reduction with no modifications. Additional modifications to the vertical and horizontal stabilizers further increase structural stiffness and reduce weight.

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I. INTRODUCTION

A. GENERAL

The Boeing-Sikorsky RAH-66 Comanche is the United States Army's newest armed reconnaissance helicopter designed to be the commander's eyes on the 21st century battlefield. Designed as a replacement for the aging OH-58 and AH-1 helicopters currently in the Army inventory, the RAH-66 will operate and survive in the lethal, high-tech battlespace of the future. Using leap-ahead technologies in the areas of Low Observability (LO), Mission Equipment Packages (MEP) and survivability, the Comanche will provide unmatched operational flexibility to the battlefield commander. Its advanced sensors and digital communications systems will allow it to serve as a forward data fusion center and provide near real time information to commanders at all levels. A photograph of the first Comanche prototype is shown in Figure 1.

Figure 1: Comanche Prototype

The Boeing Defense and Space Group's Helicopter Division of Philadelphia, Pennsylvania and United Technologies' Sikorsky Aircraft of Stratford, Connecticut were awarded the demonstration/validation (Dem/Val) phase contract for the Comanche program. These two contractors have divided the aircraft into two sections for design and fabrication responsibilities. Boeing has responsibility for the tail section of the aircraft. Sikorsky has responsibility for the forward portion of the aircraft fuselage, to include responsibility for the integration of both sections.

It is the Boeing section of the aircraft that will be the focus of this analysis. The Boeing Helicopter Company provided a finite element model of the "first flight" configuration of the tail section to be used for modification. Figure 2 shows the Boeing portion of the structure. The green section will be referred to as the tailcone and is the focus of the first part of the analysis. The blue section will be referred to as the T-tail and is the focus for the second part of the analysis. The orange section will be referred to as the shroud and will not be analyzed in this thesis.

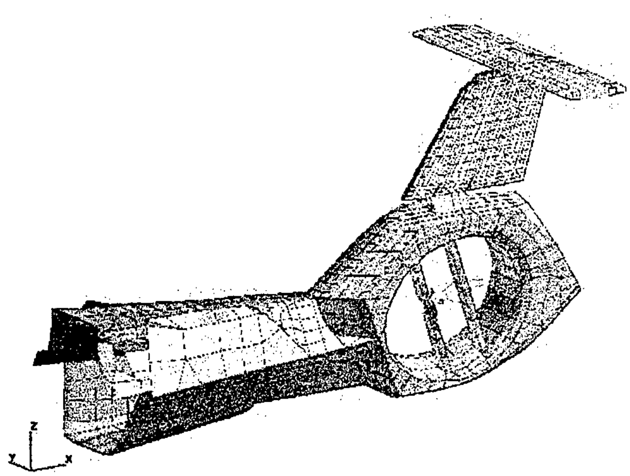

Figure 2: Comanche Tail Section

B. OVERVIEW OF THE PROBLEM

1. Tailcone Design

On the battlefield of the future, the Comanche will rely heavily on its LO capabilities. A major component of its stealth comes from its reduced radar signature through the use of radar absorbing materials (RAM) on a large portion of the outer mold line (OML), the exterior skin of the aircraft. The Comanche's stealth design requires the use of *Kevlar* and more than an inch of shielding material, such as *Nomex* or similar core material to be added between the outer and inner mold lines of the majority of the skin to meet its radar signature requirements. These requirements also limit the use of untreated graphite on the outer mold line, due to the radar reflective properties of graphite. The reduced stiffness property of these radar-absorbing materials is the cause of the problem that will be addressed by this thesis.

The first prototype of the Comanche is currently undergoing development flight testing in West Palm Beach, Florida. In its original configuration, the tail section of the prototype did not have the required stiffness to handle the expected flight loads. For the prototype to meet its structural requirements, untreated graphite, which has good stiffness properties, had to be applied to the OML of a section of the tailcone to achieve the needed stiffness. In this configuration, the radar reflective properties of the graphite do not allow the aircraft to meet its radar signature requirements.

If the cross section of the tailcone is thought of as a thin-walled cylinder under a torsional load, a simple example will explain why graphite is needed on the OML. From thin-walled torsion theory and several simplifying assumptions, the stiffness of a cylinder varies as the cube of the radius. As the load-bearing graphite is moved inward to allow for the non-load bearing RAM , the stiffness of the tailcone is greatly reduced. This loss in stiffness could be offset by increasing the thickness of the underlying graphite or by increasing the overall radius of the tailcone.

Unfortunately, these options would add to the weight of the tail section. The Comanche's current center of gravity is already aft of the optimal point, requiring extra weight in the nose of the aircraft. Any additional weight in the tail section would necessitate more ballast in the nose of the aircraft, causing an undesirable increase in the total weight of the aircraft. Fortunately, the Comanche tailcone structure is not a simple cylinder and has underlying structure that can be modified.

2. T-Tail Fitting Design

The Comanche has a requirement to be transported by a C-130 'Hercules' aircraft. To meet this requirement, the current tail-fold design includes three fittings. Figure 3 shows the current tail-fold design. The vertical stabilizer root fitting is located between the shroud and vertical stabilizer and is composed of four bolts that allows the T-tail to rotate by removing two of the bolts. The vertical stabilizer attach fitting is located between the vertical and horizontal stabilizers and attaches the two stabilizers together. The horizontal stabilizer fold fitting is located on the port side of the horizontal stabilizer near the center of the stabilizer and allows the horizontal stabilizer to be folded.

The current tail-fold design causes the fittings to carry primary loads that are then concentrated in the spars of the vertical stabilizer. To carry these loads, the spars must be made of graphite causing an unacceptable antenna performance penalty.

The Boeing engineers have developed a proposed tail-fold design to eliminate this problem. Figure 4 shows the new proposed design. In the proposed design, the horizontal stabilizer fold fitting is removed. The vertical stabilizer root and attach fittings are modified to rigidly connect the spars in the vertical stabilizer to bulkheads in the horizontal stabilizer and shroud. To meet the C-130 transportability requirement, an external hinge will fasten to attachment points on the vertical stabilizer and shroud. The vertical stabilizer root fitting will be designed to allow the entire T-tail to rotate on the external hinge.

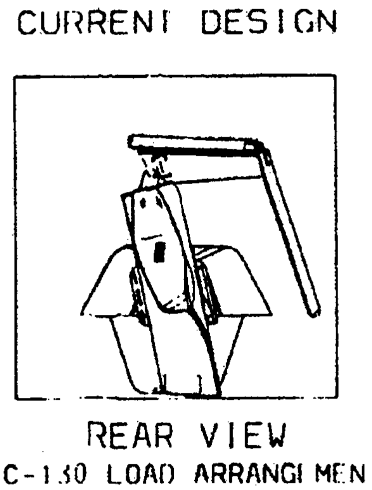

Figure 3: Current Tail-Fold Design

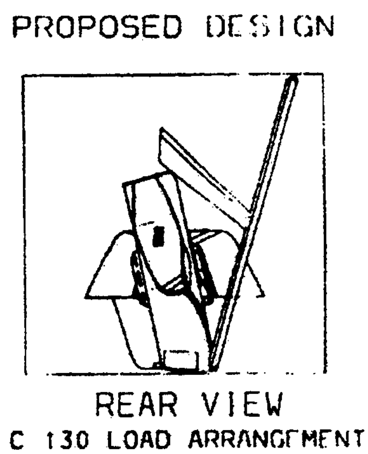

Figure 4: Proposed Tail-Fold Design

II. PURPOSE OF RESEARCH

This research is divided into two parts. The first part of this research is to design and analyze currently proposed structural modifications that would increase the tailcone's torsional stiffness. These modifications are then added to earlier modifications developed and analyzed here at the Naval Postgraduate School (NPS). This earlier analysis was conducted by a MAJ Vincent Tobin in his thesis 'Analysis of Potential Structural Design Modifications for the Tail Section of the RAH-66 Comanche Helicopter' completed in September, 1997

As stated earlier, Boeing provided a NASTRAN finite element model of the Comanche representing the aircraft structure at the time of its first flight in May of 1996 to be used for modification. This original model simulates the prototype aircraft with the graphite on the OML and has the required structural stiffness. Modifications will be compared to a baseline model to determine the percent increase in torsional and bending stiffness.

The goal of this part of the thesis is to combine the proposed modifications in order to allow the replacement of the graphite on the OML of the tailcone with RAM and achieve the stiffness of the prototype.

The second part of this research is to design and analyze currently proposed structural modifications to the Comanche's horizontal and vertical stabilizers that would incorporate the proposed tail-fold design changes. The analysis goal is to determine any weight savings and changes in selected stiffnesses that would effect the design.

While this research deals with static load cases, analysis of static cases is done strictly to provide insight into the likely dynamic implications of structural modifications. The goal, ultimately, is to produce design modifications that will optimize natural frequency placement without increasing gross weight and without increasing infrared and radar signatures. Typically, structural stiffening will raise natural frequencies provided there is no significant increase in weight associated with the stiffening [Ref. 1].

III. THESIS DEVELOPMENT

A. FINITE ELEMENT THEORY

1. Finite Element Method

The complex design of most modern aerospace structures makes it almost impossible to analyze the effects of forces applied to them. For analysis purposes, these complex structures can be decomposed into individual structural members that can usually be idealized using beam bending theory, torsion theory, plate theory or shear flow methods. However, the presence of discontinuities such as thickness and cross-sectional variation, cutouts, and joints adds to the difficulty. [Ref. 2]

This research is based on the Finite Element Method (FEM). The FEM provides the basis for algorithms that can efficiently analyze complex structures such as the tail section of the Comanche. In the late 1950s, with the advent of the digital computer, the Finite Element Stiffness Method evolved to handle these complex structures. The finite element method views the complete structure as an aggregate of a finite number of simple base elements whose deformation response to applied loads is relatively easily determined as compared with the complex structure. [Ref. 3]

These elements, defined by nodes, can be analyzed separately for equilibrium and then tied back together into the original structure. By imposing equilibrium conditions on the applied forces while simultaneously ensuring compatibility of the nodal displacement, a unique solution can be found for the entire structure. [Ref. 2]

As the complexity of the structure increases, the size of the linear system that must be solved increases dramatically, leading to the need for computer software programs to handle the calculations. This thesis uses two powerful software packages, NASTRAN and PATRAN, to analyze structural stiffness results based on the geometric and material properties of the structural model of interest.

2. NASTRAN

The National Aeronautics and Space Administration (NASA) funded initial development of NASTRAN in the 1960s. The word NASTRAN is an acronym for NASA STRuctural ANalysis. NASTRAN was one of the first programs designed to use the finite element method to analyze structural models. [Ref. 3]

Now owned and distributed by the MacNeil-Schwendler Corporation (MSC), it has evolved into the industry's leading finite element analysis program. Version 69 is the version used for this research.

3. PATRAN

MacNeil-Schwendler also produces PATRAN to provide an integrated computer-aided engineering (CAE) environment. PATRAN software is both a preprocessor and postprocessor usable with several finite element analysis codes, including NASTRAN. Its capabilities include geometry modeling, mesh generation, analysis data integration, analysis simulation and results display and evaluation. [Ref. 4]

The menu-driven graphical user interface makes model analysis relatively easy when compared with working directly with the NASTRAN code. All finite element models and results plots presented in this document were generated using PATRAN Version 6.2. [Ref. 4]

B. MODEL DEVELOPMENT

The first step in the process of analyzing the changes in structural stiffness is to develop the NASTRAN models representing the proposed modifications. Figure 5 shows a finite element mesh of the original model of the tail section provided by Boeing. This model represents the aircraft in its first flight configuration on 4 May 1996. The remaining ten models are variations on this original structure. Using PATRAN software, model changes were made by changing geometry, material properties, or both

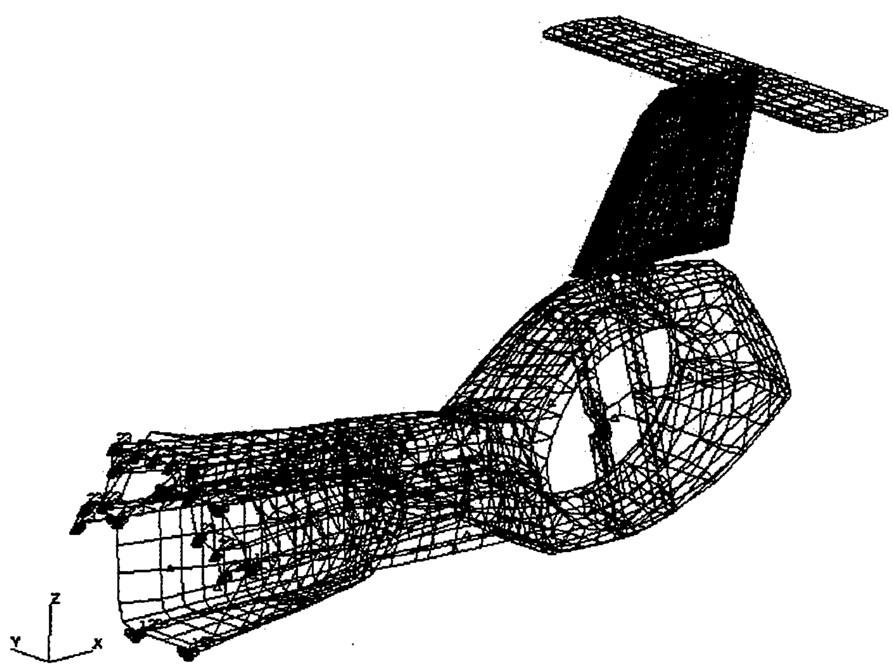

Figure 5: Finite Element Model of Comanche Tail Section

The model in Figure 5 is called a "cantilevered" model because displacement boundary conditions are imposed at the forward edge of the tail section. These boundary conditions are represented graphically by arrowheads. The tip of each arrowhead rests on the point or node that is fixed. The direction of the arrowheads as well as the numerals (1, 2, or 3) adjacent to the constrained nodes indicate the translational constraints in the 1, 2, or 3 (x, y, or z respectively) directions. [Ref. 5]

Not all the nodes are constrained in the same way. Boeing developed this configuration of boundary conditions to model the interface between the Boeing and Sikorsky sections of the aircraft. This boundary condition arrangement will be used for analysis of all structural modifications to the tailcone models.

A total of twelve models are discussed here. Each model will be identified by its shortened name that appears in parenthesis after their respective headings. The models are separated into two main categories. The first category includes all modifications to the tailcone section. This category is further broken down into three subcategories that are described in detail. The second category includes the currently proposed modifications to the T-tail section.

1. Tailcone Modifications

As stated earlier, MAJ Vincent Tobin, a recent graduate of the Aeronautical Engineering curriculum at NPS, conducted similar analyses on three proposed modifications to the tailcone. His work concentrated on the tailcone section for two reasons. The first reason is that the tailcone contains the area where the graphite was added to the OML to increase the structural stiffness. The second reason is that his work utilized an earlier version of PATRAN that was unable to analyze the solid elements modeled in the T-tail section. Because of this limitation, his analysis was restricted to the tailcone section. Since this first part of the model development builds on his work, the following eight models deal strictly with the tailcone section.

a. Earlier Modifications

The following subsection paraphrases MAJ Tobin's baseline model and three of his modifications. For more information on his analysis, please refer to his thesis, which is listed as reference five at the end of this thesis.

(1) Baseline Model (BASE_RED). This first model is aptly named because it serves as the baseline for the proposed modifications to the tailcone section. This baseline model is a 'reduced' version of the original tail section model and is shown in Figure 6. It is reduced because the shroud and T-tail sections are not displayed. To fully analyze the effects of the modifications in this area, the test load forces were applied to the Aft Tailcone Bulkhead. Therefore, while these two sections still exist in the model, they displace as a rigid body and contribute no stiffness with respect to the boundary conditions and applied loads.

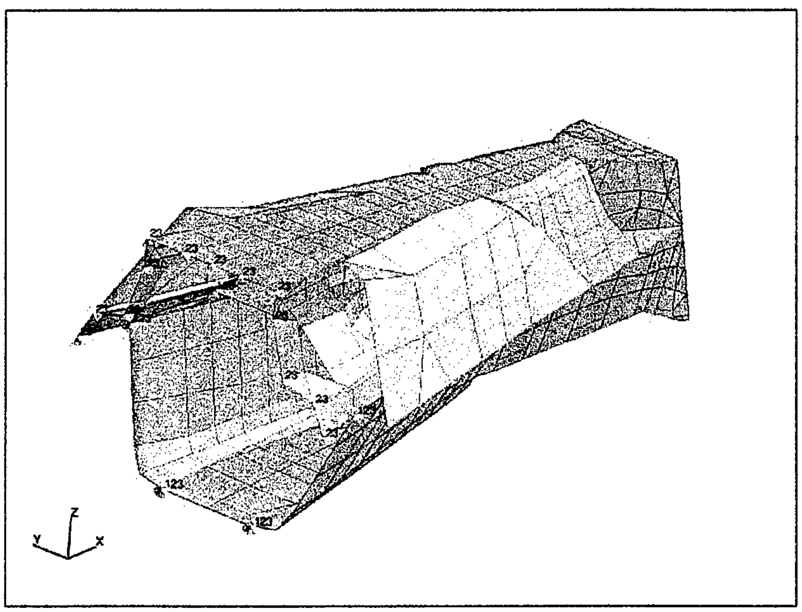

Figure 6: Baseline Model (BASE_RED). From Ref. 5

In addition, the PATRAN software uses color contour plots to show the magnitudes of the displacements, stresses, or strains on the models due to the applied forces. The exhaust covers, displayed in blue in Figure 6, are considered non-structural because their load-carrying capability is negligible and will not be displayed for the models of the tailcone section. Displaying the effects of the applied forces on the structural elements under the exhaust covers provides far more useful information. Although the exhaust covers are not displayed, their small structural influence is calculated by NASTRAN and incorporated into the displayed results. Figure 7 shows the tailcone with the exhaust covers not displayed. [Ref. 5]

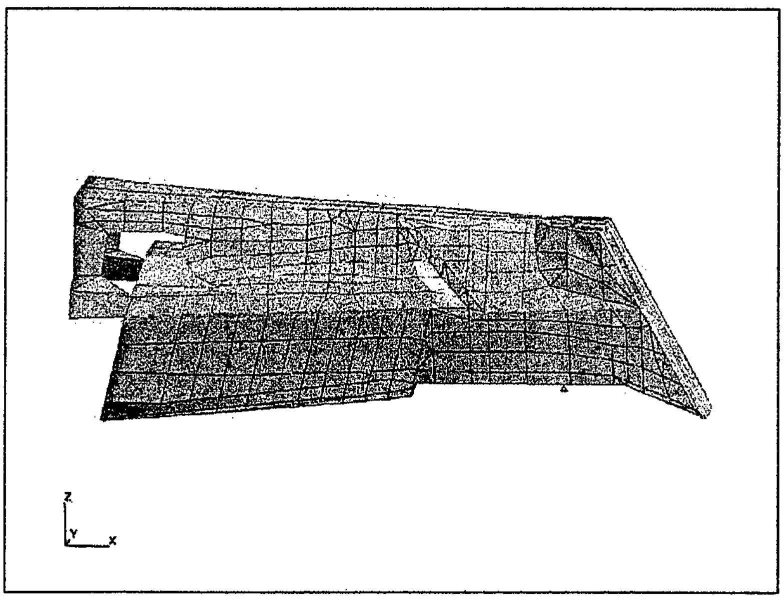

Figure 7: BASE_RED with Exhaust Covers Not Displayed. From Ref. 5

(2) Baseline Model with Kevlar on the OML (BASE_KEV). This modification is the same as BASE_RED except that it replaces the graphite on the OML with RAM to enable the design to meet radar signature requirements. This model is analyzed only to obtain another baseline set of structural stiffnesses for a structure made of materials likely to meet radar signature requirements. This set of structural stiffnesses will serve as another basis of comparison. [Ref. 5]

(3) Bulkhead Section Modification (BULK_MOD). This model is the BASE_RED model with structural modification confined to the forward Tail Landing Gear Bay Bulkhead (TLGBB) and structure in the immediate vicinity. The TLGBB spans most of the tailcone cross-section and defines the forward wall of the tail landing gear bay. Structurally, its main purpose is to transition loads from the upper torque box aft of the TLGBB to the large closed section that encompasses almost the entire tailcone cross section forward of it. The location of the TLGBB is shown in red in Figure 8. [Ref. 5]

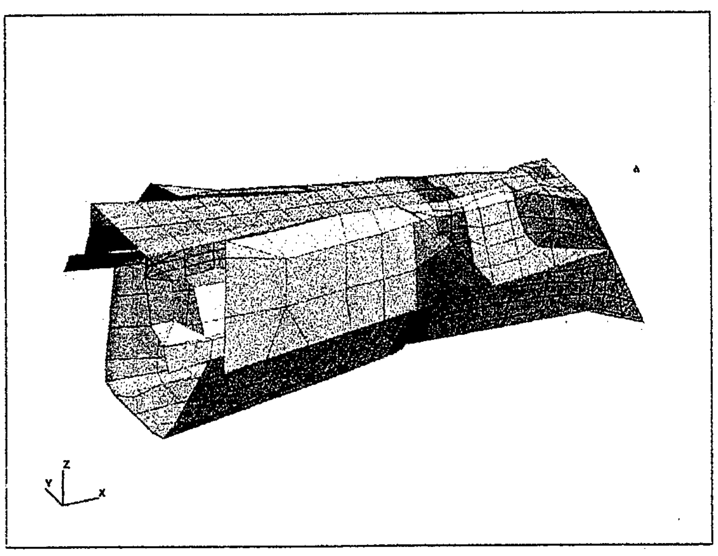

Figure 8: TLGBB Location in the Tailcone. From Ref 5

The intent of this modification was to stiffen the structure by connecting the structural component of the aft, upper tailcone skin to the TLGBB. This modification changed the shape of the bulkhead from resembling an "hourglass" to resembling a "mushroom. Figure 9 shows the TLGBB as modified for the BULK_MOD model. Elements displayed in green are those of the Baseline TLGBB. Elements in red have been added for the Bulk-Mod Model. This modification required other structural modifications near the bulkhead that will not be discussed in this thesis. [Ref. 5]

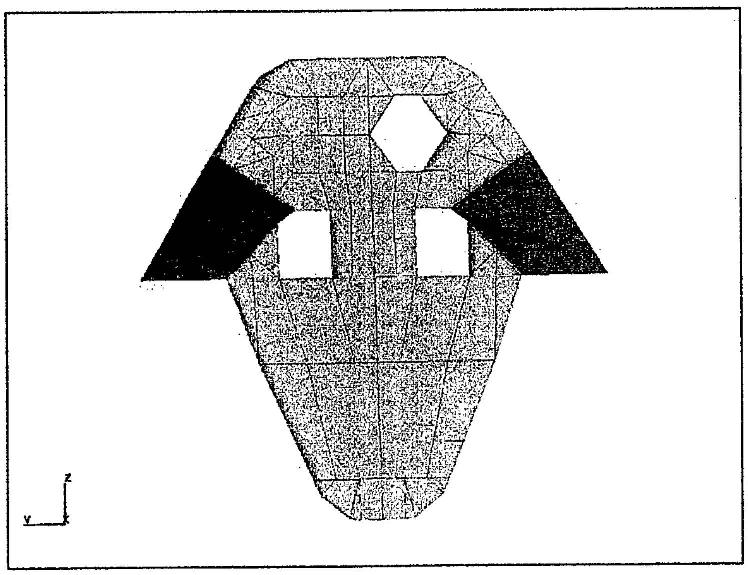

Figure 9: TLGBB as modified for BULK_MOD. From Ref. 5

(4) Aft Tailcone Section Modification (CONE_MOD). This model is the BASE_RED model with the structural modifications confined to the upper tailcone, aft of the TLGBB. The main element of the upper section is the Upper Walking Deck, which connects the TLGBB to the Aft Tailcone Bulkhead. Structurally, its main purpose is act as the top of a 'torque box' that carries most of the loading from the T-tail section.

The intent of this modification was to increase the enclosed cross-sectional area of the upper tailcone. Figure 10 shows in red the added elements needed to model this new structure. [Ref. 5]

This concludes the summary of the previous work conducted by MAJ Tobin.

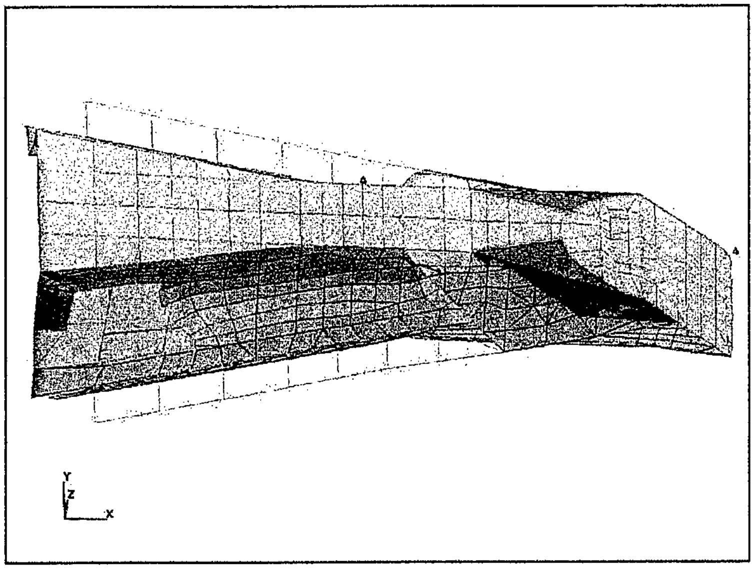

Figure 10: Tailcone as modified for CONE_MOD. From Ref 5

b. Current Modifications

The following subsection describes the currently proposed modifications to the tailcone that were analyzed in this thesis. Appendix A is a listing of all changes necessary to produce these new models. The data in Appendix A includes a listing of all the elements that were added or deleted to include their associated nodes and material properties. Also listed are the coordinate locations of any nodes that were moved or added to create new elements or modify existing elements.

(1) Tail Landing Gear Bay Modification 1 (BAY_MOD 1). This first new model is the BASE_RED model with the structural modifications confined to the Tail Landing Gear Bay (TLGB). Because the doors are not structural, the cross-section of the TLGB is structurally an open section and with the landing gear extended and the doors open, it is physically an open section. The TLGB is depicted in red in Figure 11.

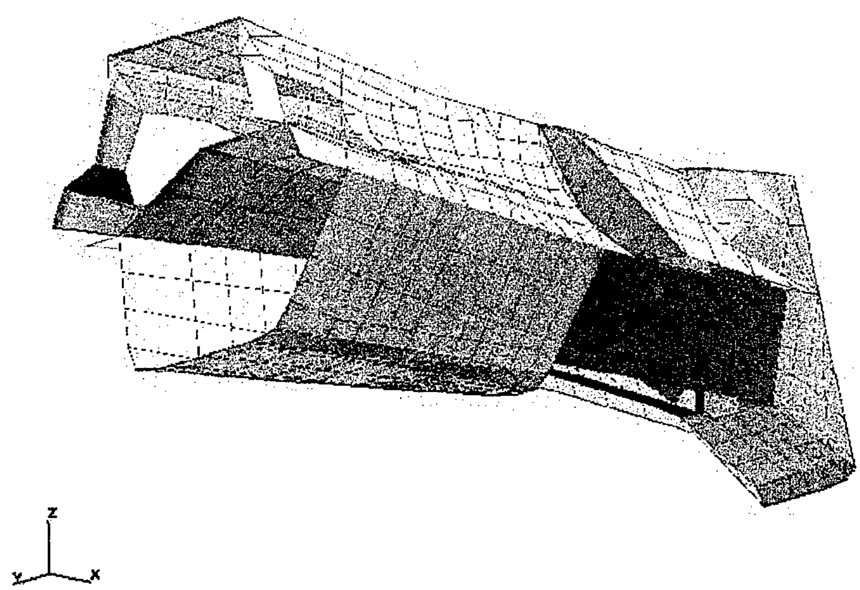

Figure 11: Location of the Tail Landing Gear Bay

The TLGB is defined by the Water Line 3160 Deck as its top, the lower half of the TLGBB as its front, the aircraft skin as its sides and its bottom is open. The aft wall of the TLGB is open to allow for movement of the tail landing gear. Structural longerons run along the inside of both sides of the TLGB and are the point of

attachment for the proposed modification. Figure 12 shows a cut away of the TLGB. The outline of the TLGB is shown in black and the longerons are shown in light blue. The longerons are made up of 11 plies of graphite and provide structural support in the TLGB.

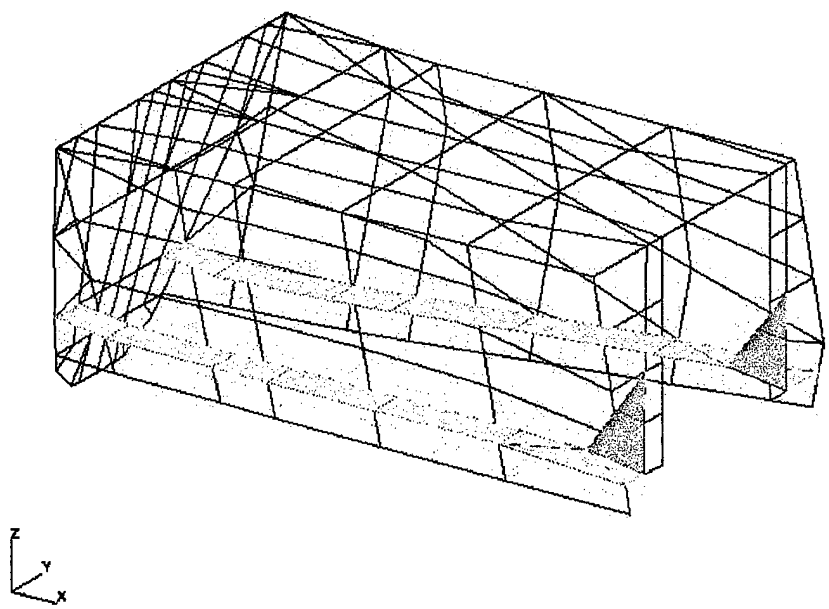

Figure 12 Cut Away View of the TLGB showing the Longerons

The longerons vary in width as they run along the sides of the skin and their inner edges do not form a straight line. At the aft end of each longeron, a wedge shaped support connects the longerons to the aft wall of the TLGB. For BAY_MOD 1, these supports were removed and the aft sections of both longerons were replaced to straighten them out.

In addition, vertical panels were attached from the inner edges of the longerons to the Water Line 3160 Deck. These panels are perpendicular to the inner edges of the longerons and run from the TLGBB to the aft wall. Figure 13 shows the proposed modifications to the TLGB in red. Several of the nodes in a portion of the TLGBB were moved to fully connect the shear walls to the TLGBB. Moving the nodes required replacing of several elements in the TLGBB and these new elements are also shown in red.

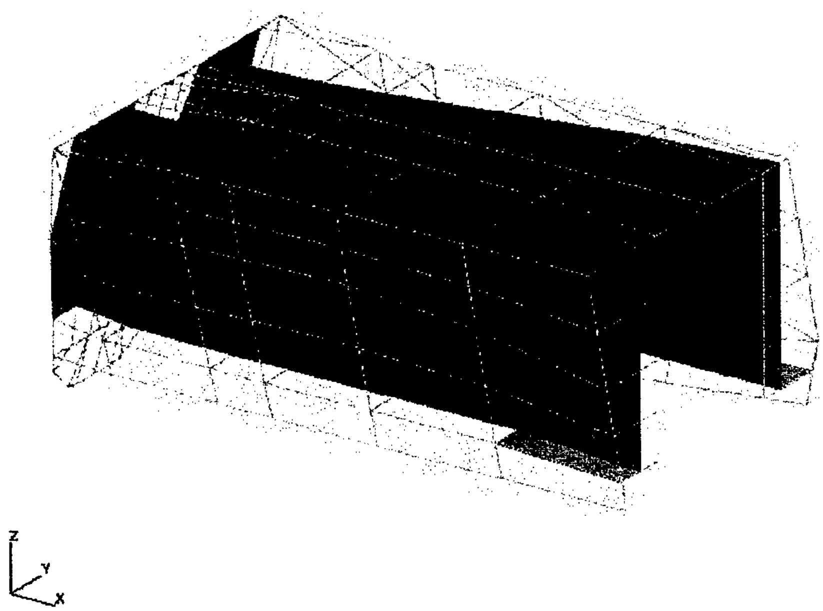

Figure 13: TLGB as modified for BAY_MOD 1

Unfortunately, since the inner edges of the longerons are not straight, the vertical shear walls are not smooth but have "wrinkles" in them. The shear walls and aft section of each longeron are composed of the same material as the existing

longerons. The new elements in the TLGBB are made of the same materials as the original elements that they replaced.

The intent of this modification was to create vertical shear walls that formed two smaller "torque boxes" on both sides of the TLGB. Since the TLGB is an open section that does not carry torsional loads well, these shear walls were designed to increase the torsional stiffness of the TLGB.

(2) Tail Landing Gear Bay Modification 4 (BAY_MOD 4). This second new model is a variation on BAY_MOD 1. Again, the structural modifications are confined to the TLGB. For BAY_MOD 4, the wedge-shaped supports were removed and the aft sections of both longerons were replaced. In addition, two additional longerons were added along the inner edges of the TLGB above the original longerons. Vertical panels were attached from the inner edges of the original longerons to the inner edges of the new longerons. These panels are also perpendicular to the inner edges of both sets of longerons and run from the TLGBB to the aft wall.

In addition, the inner edges of the original longerons were modified to form a straight line from the TLGBB to the aft wall. This modification was intended to remove the "wrinkles" associated with the shear walls in BAY_MOD 1and to reduce the added weight of the modification. Figure 14 shows the proposed modifications to the TLGB in red. The original longerons continue into the area forward of the TLGBB. Because the inner edges of the original longerons were modified, the first elements of both longerons forward of the TLGBB also had to be modified. The shear walls and aft section of each longeron are composed of the same material as the existing longerons. The modified elements in the section forward of the TLGBB are made of the same material as they were originally composed.

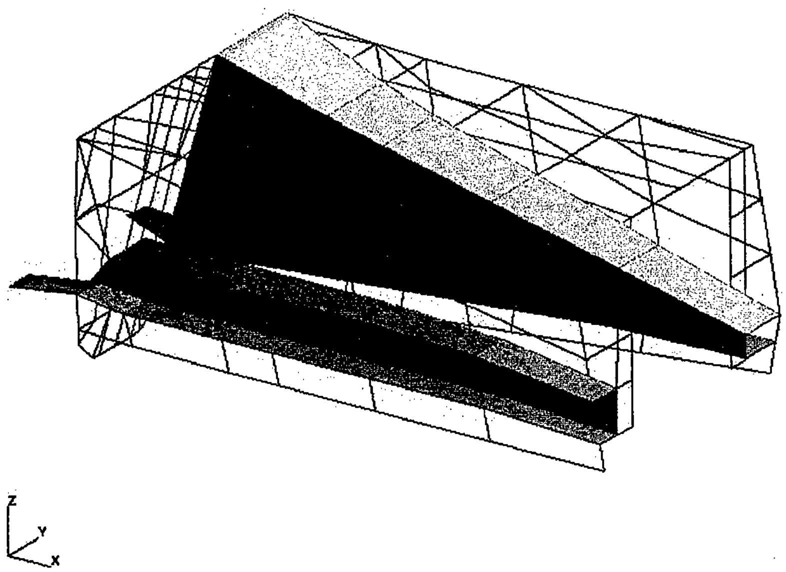

Figure 14: TLGB as modified for BAY_MOD 4

c. Combined Modifications

The following subsection describes the combination of the earlier modifications and the currently proposed modifications to the tailcone into one model. For reasons that will be explained in the Results section of this thesis, only BAY_MOD 4 was included in these combination models.

(1) Combination Modification 1 (ADD_MOD). This model gets its name because it is the combination of BULK_MOD and CONE_MOD *added* to BAY_MOD 4. ADD_MOD is simply the BASE_RED model with the structural

modifications of BULK_MOD, CONE_MOD and BAY_MOD 4 combined into a single model. The material properties used are those of each of the different modifications.

(2) Combination Modification 2 (KADD_MOD). This model has exactly the same outer mold line geometry as the ADD_MOD model. The material properties are different. The aft tailcone skin for this model has RAM properties that are designed to achieve the reduced radar signature required. This skin configuration has four plies of graphite on the inner mold line, 33 millimeters of core material and two plies of Kevlar on the outer mold line. This compares to the BASE_RED model where the skin was composed of two plies of graphite on the inner mold line, 12.7 millimeters of core, and six plies of graphite on the outer mold line.

2. T-Tail Modifications

This thesis uses version 6.2 of PATRAN. Version 6.2 is the latest version of PATRAN and has the capability to analyze the solid elements modeled in the T-tail section. Therefore, this next part of the model development is not restricted to the tailcone section. Unlike the goal of the previous part, the analysis goal for this part is to determine any weight savings and changes in selected stiffnesses that would effect the design. Therefore, new baseline models must be established.

This second category includes the currently proposed modifications to the T-tail section. The following four models are divided into two subcategories that focus on different parts of the T-tail section of the helicopter. The first two models deal with proposed modifications to the horizontal stabilizer. The last two models deal with proposed modifications to the vertical stabilizer.

a. Horizontal Stabilizer Modifications

As stated earlier, The Comanche has a requirement to be transported by an Airforce C-130 'Hercules' aircraft. To meet this requirement, the current tail-fold design requires a horizontal stabilizer fold fitting, (i.e. a hinge), located on the port side of the horizontal stabilizer near the center of the stabilizer to allow the horizontal stabilizer to be folded. Figure 15 shows a close up of the horizontal stabilizer with the fitting in red. Only the structural members of the fitting is shown and not the complete fitting.

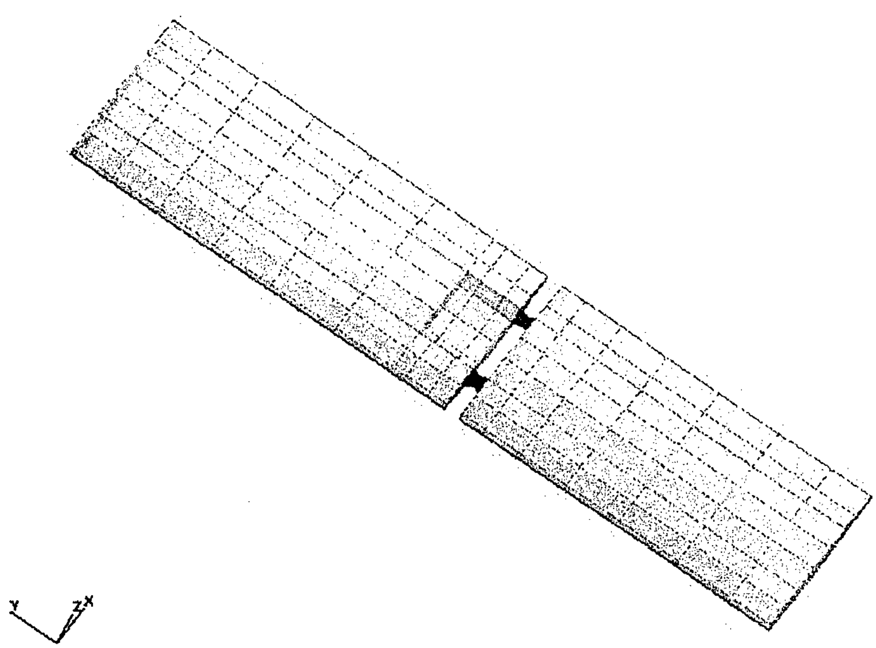

Figure 15: Current Horizontal Stabilizer Tail-Fold Design

The current tail-fold design is unacceptable and the Boeing engineers have developed a proposed tail-fold design that removes the horizontal stabilizer fold fitting. The following two models address his new design.

(1) Horizontal Stabilizer Reduced (STAB_RED) This model serves as the baseline for the proposed modification to the horizontal stabilizer. This baseline model is a "reduced" version of the original tail section model and is shown in Figure 16. This model is not like the BASE_RED model where some sections of the tail are not displayed but still involved in NASTRAN analysis. Because this analysis was narrowly focused on the effect of the proposed modification on the symmetrical vertical bending of the horizontal stabilizer, everything but the horizontal stabilizer has been deleted from the NASTRAN database.

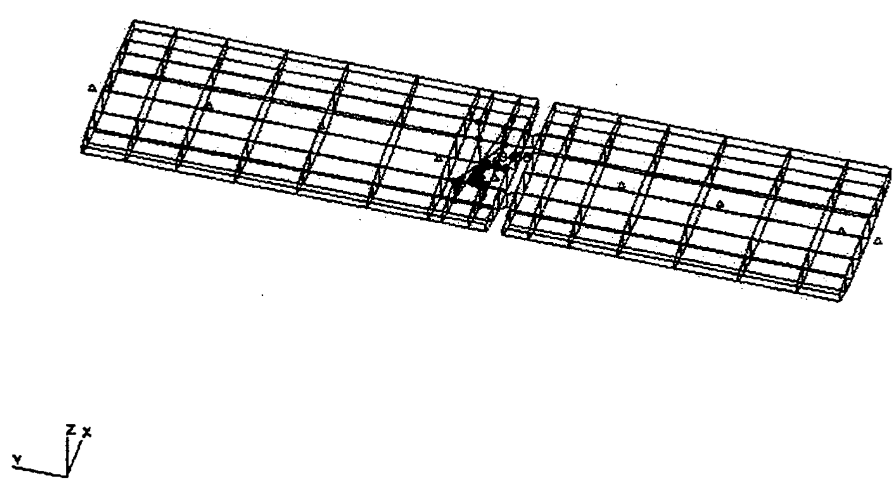

Figure 16: STAB_RED with Boundary Conditions Imposed

In addition, the horizontal stabilizer has been rigidly fixed at the location of its attachment to the vertical stabilizer. This was done to eliminate any effects caused by other elements of the tail section. In Figure 16, the stabilizer is fixed in all translational and rotational directions as indicated by the arrows and numbers. To simplify the model, a multi-point constraint (MPC) was used to apply the boundary conditions to all the affected nodes. This arrangement models a perfectly rigid test fixture attached to the stabilizer. All nodes attached via MPC to the constrained node maintain their relative positions to one another after application of loads. This boundary condition arrangement will be used for analysis of the horizontal stabilizer models.

(2) Horizontal Stabilizer Modification (STAB_MOD). This model is the STAB_RED model with the structural modifications confined to the fold fitting. The structural elements of the fold fitting were removed. The open section created was filled with the same material that borders the open section to produce a horizontal stabilizer that is one continuous piece. Figure 17 shows the added elements in red.

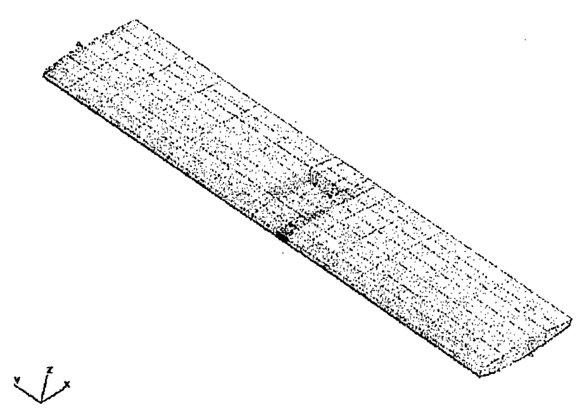

Figure 17: Horizontal Stabilizer as modified for STAB_MOD

b. Vertical Stabilizer Modifications

The final two models were developed to investigate the reduction in stiffness caused by removing one of the three spars located in the vertical stabilizer. In the proposed tail-fold design, the vertical stabilizer root and attach fittings will be modified to rigidly connect the spars in the vertical stabilizer to bulkheads in the horizontal stabilizer and shroud. Part of this modification will be to remove one of the spars. It is hoped that the rigid connection of the horizontal stabilizer to the shroud through the vertical stabilizer will recover the reduction in stiffness caused by the removal of one spar.

Unfortunately, detailed drawings of the new fittings have not been produced at this time. Without these drawings, the fittings could not be modeled correctly. Therefore, the effects on stiffness of the rigid connection could not be analyzed. The following two models are designed to address the reduction in stiffness due to the removal of a spar only. In addition, the proposed modification can be incorporated into future modifications when detailed drawings of the proposed fittings are made available.

(1) Vertical Stabilizer Reduced (VFIN_RED) This model serves as the baseline for the proposed modification to the vertical stabilizer. This baseline model is a "reduced" version of the original tail section model and is shown in Figure 18. This model is similar to the STAB_RED model because this analysis was narrowly focused on the effect of the proposed modification on the loss in stiffness in the vertical stabilizer. Everything but the vertical stabilizer has been deleted from the NASTRAN database.

This time the vertical stabilizer has been rigidly fixed along the entire bottom of the stabilizer at the proposed location of its attachment to the shroud. The stabilizer is again fixed in all translational and rotational directions as indicated by the arrows and numbers. An MPC was used to apply the boundary conditions to all the affected nodes. This boundary condition arrangement will be used for analysis of the vertical stabilizer models.

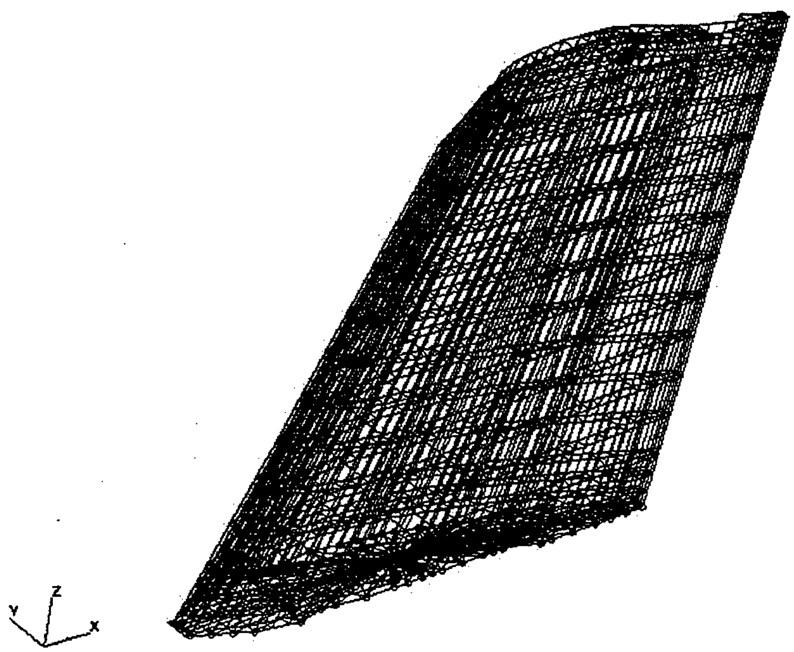

Figure 18: VFIN_RED with Boundary Conditions Imposed

(2) Vertical Stabilizer Modification (VFIN_MOD). This model reproduces the exterior geometry of the VFIN_RED model. In order to reduce the number of spars, a geometric model of the original vertical stabilizer was produced using PATRAN. With only minor changes at the top and bottom the modified vertical fin replicates the exterior of the original vertical stabilizer. Figure 19 shows this replication. The mid-slice of the original elements are displayed in green. The superimposed black wire frame shows the modified stabilizer. As can be seen from Figure 19, the outline of the VFIN_MOD model matches the outline of the VFIN_RED model.

In VFIN_RED, the Boeing engineers used in excess of 30 different material properties to optimize weight reduction. Due to time constraints, VFIN_MOD did not go through this same process. Therefore the number of different material properties is simplified to only 13. These material properties were selected because they represented the majority of the material properties used in VFIN_RED. A complete listing of the material properties used in VFIN_MOD is included in Appendix A.

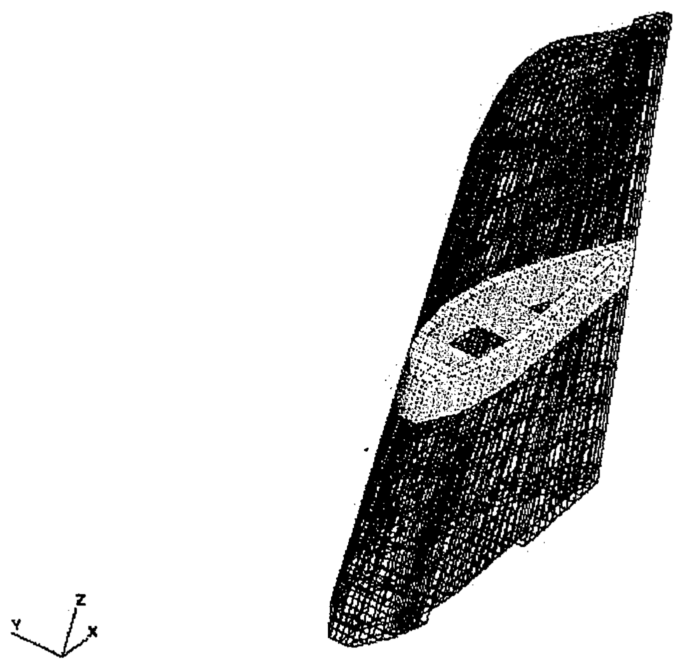

Figure 19: VFIN_MOD Superimposed on VFIN_RED

On the following pages, Figures 20 and 21 show the spar configuration in the VFIN_RED model and the VFIN_MOD model respectively.

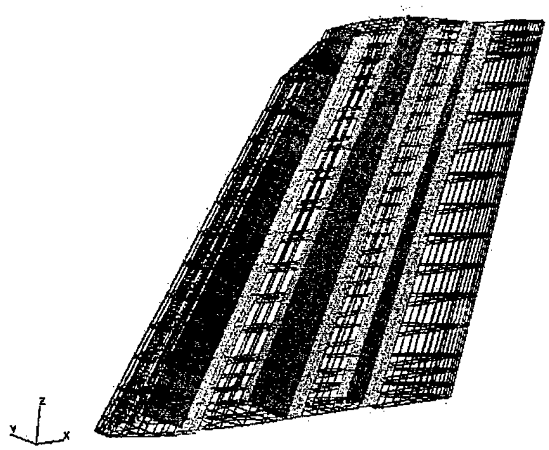

Figure 20: VFIN_RED Spar Configuration

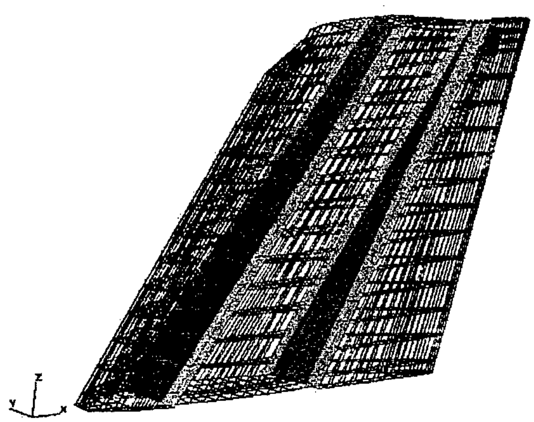

Figure 21: VFIN_MOD Spar Configuration

C. LOAD CASES

The actual aerodynamic forces acting on the aircraft while in flight is difficult to determine. Only detailed flight-testing will enable the determination of the various combinations of forces and moments acting on the tail section. However, since this is a static load analysis with assumed linear responses, the designs will be assessed by changes in stiffness and not displacements due to flight loads.

Because this research attempts to analyze several different sections of the tail, several load cases are created for the different areas of analysis. Under actual flight conditions, loads transmitted through the tail section would be distributed throughout the entire structure. These forces and moments would be transmitted through the tail section as distributed loads and not point forces or moments. An MPC was used to allow an applied point force or moment to be distributed across the affected cross-section to model these distributed loads

1. Tailcone Load Cases

Since the modifications to the tailcone section builds on earlier work, those load cases will be applied to the tailcone. The following subsection paraphrases MAJ Tobin's load cases. The applied load cases for the tailcone are: a negative x-direction moment, a positive y-direction force and a negative z-direction force. The point of application is the node nearest to the center of rotation of the aft bulkhead of the BASE_RED model. A rigid MPC was attached to all nodes of the aft bulkhead perimeter and to the load application node. For more information on his analysis, please refer to his thesis, which is listed as reference five at then end of this thesis.

a. Long Axis Moment

The primary moment in the negative x-direction on the tailcone occurs due to the aerodynamic force on the vertical stabilizer. The separation of the tailcone and vertical stabilizer center of pressure creates the moment arm. The actual aerodynamic loads on the vertical tail are transmitted to the tail as both a shear force and a rolling moment. Here these load cases are treated separately and only the moment is applied for this load case. The applied load is 10,000 Newton-Meters. [Ref. 5]

b. Lateral Force

The positive y-direction force on the aft end of the tailcone is due to anti-torque forces applied to the vertical tail and transmitted through the structure to the tailcone. This load case is designed to examine the lateral bending stiffness of the tailcone. The applied load is 5000 Newtons. [Ref. 5]

c. Vertical Force

The negative z-direction force occurs in high-speed forward flight where downward aerodynamic force is generated on the horizontal tail to level the fuselage attitude and reduce drag. The applied load is 5000 Newtons. [Ref.5]

2. Horizontal Stabilizer Load Case

Because the focus of the analysis of the horizontal stabilizer was restricted to the symmetrical vertical bending mode, only one load case was applied. A 50 Newton load was applied to both ends of the stabilizer to the nodes at the approximate center of rotation. A rigid MPC on both ends attached all the perimeter nodes of the each end to the load application nodes.

3. Vertical Stabilizer Load Cases

The tailcone section load cases from section 1 were also applied to the vertical stabilizer. However, the point of application was different. The load cases were applied to the node at the approximate center of the top of the vertical stabilizer to simulate the transmittal of forces from the horizontal stabilizer through the upper fitting. A rigid MPC attached several of the perimeter nodes to the load application node to simulate the fitting.

IV. RESULTS AND ANALYSIS

The results of the analysis are presented in numerical form in the tables below. Sample PATRAN contour plots of strain energy density will be displayed to highlight certain aspects of the analysis.

A. TAILCONE RESULTS

The results of the BASE_RED and BASE_KEV are shown for comparison to the new modifications. To maintain consistency with the earlier analysis performed by MAJ Tobin, the numerical results are presented in two separate tables. The first table provides information on selected stiffnesses in SI units. The second table presents the same data normalized to the BASE_RED model results.

1. BAY_MOD Model Results

Table 1 presents the results of analysis of the two BAY_MODs. The stiffness of each model in torsion, lateral bending and vertical bending is presented for comparison. The torsional stiffness is defined as the applied moment per degree of x-rotation of the load application node. The bending stiffnesses are defined as the applied force per unit of y-displacement or z-displacement of the load application node. Table 2 presents the same data as the previous table normalized to the BASE_RED model results.

Model	Torsion (N-m)/degree	Horizontal Bending (N/m)	Vertical Bending (N/m)
BASE_RED	25,822	2,634,559	1,905,910
BAY_MOD 1	27,249	2,741,849	2,072,743
BAY_MOD 4	27,477	2,728,413	1,989,323

Table 1: BAY_MOD Model Stiffnesses in SI Units

Model	Torsion	Horizontal Bending	Vertical Bending
BASE_RED	1.000	1.000	1.000
BAY_MOD 1	1.055	1.041	1.087
BAY_MOD 4	1.064	1.035	1.043

Table 2: BAY_MOD Model Stiffnesses Normalized to BASE_RED Results

One of the reasons why BAY_MOD 4 has a higher torsional stiffness can be explained using the following two figures. Figures 22 and 23 show strain energy density distribution plots produced by PATRAN. These contour plots show the strain energy per unit volume as a function of position. The colors indicate the magnitudes as shown on the bar on the right side of the figure. Higher values indicate "soft spots" on the structure.

Figure 22 shows the starboard side of a cut away view of the TLGB. This is a results plot of BAY_MOD 1 subjected to the torsional load case described earlier. The colors indicate a relative soft area running diagonally from lower left to upper right. That weak area is where one of the added longerons of BAY_MOD 4 is attached to the skin.

Figure 23 shows the same view of BAY_MOD 4 subjected to the same load case. The colors indicate that the weak area has been almost completely eliminated. In

BAY_MOD 1, the "torque box" created on the starboard side was defined by the Waterline 3160 Deck on top, the starboard longeron on bottom, the aircraft skin as one side, and the starboard shear wall as the other side. In BAY_MOD 4, this "torque box" was defined the same except that the added starboard longeron defined the top. In both starboard "torque boxes", the outer skin was made of the weakest material. Also, the vertical shear walls are perfectly straight in BAY_MOD 4, which increases their torsional stiffness. These factors help explain why BAY_MOD 4 has a higher torsional stiffness.

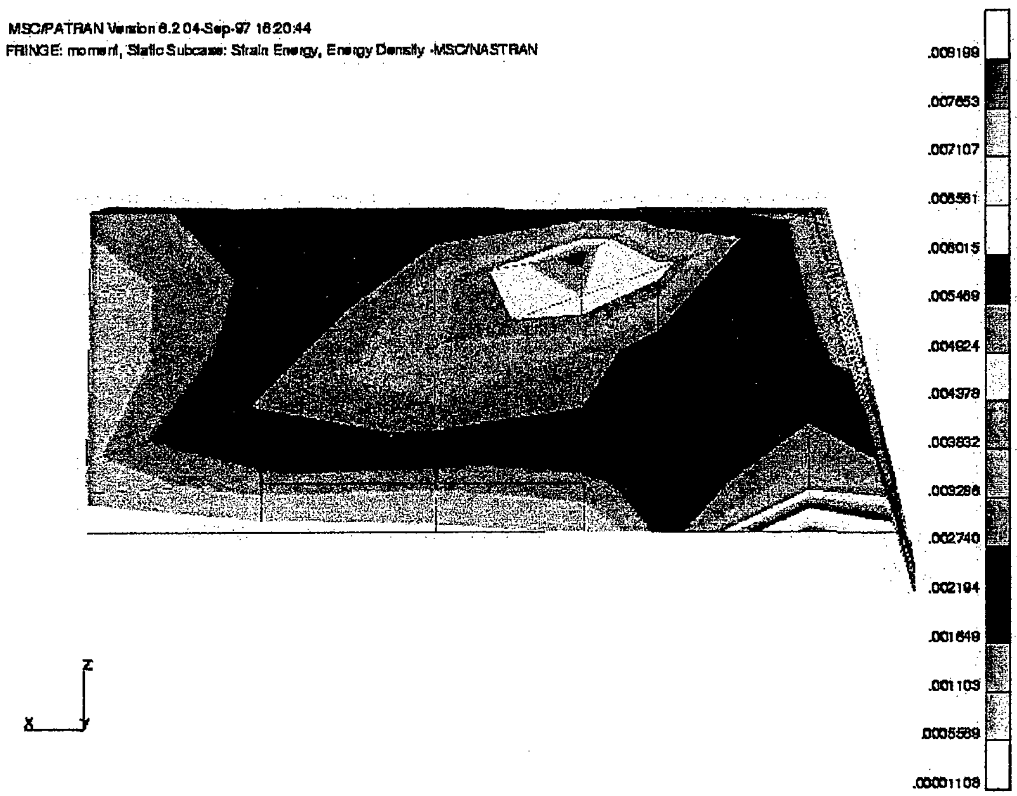

Figure 22: BAY_MOD 1 Strain Energy Density Distribution

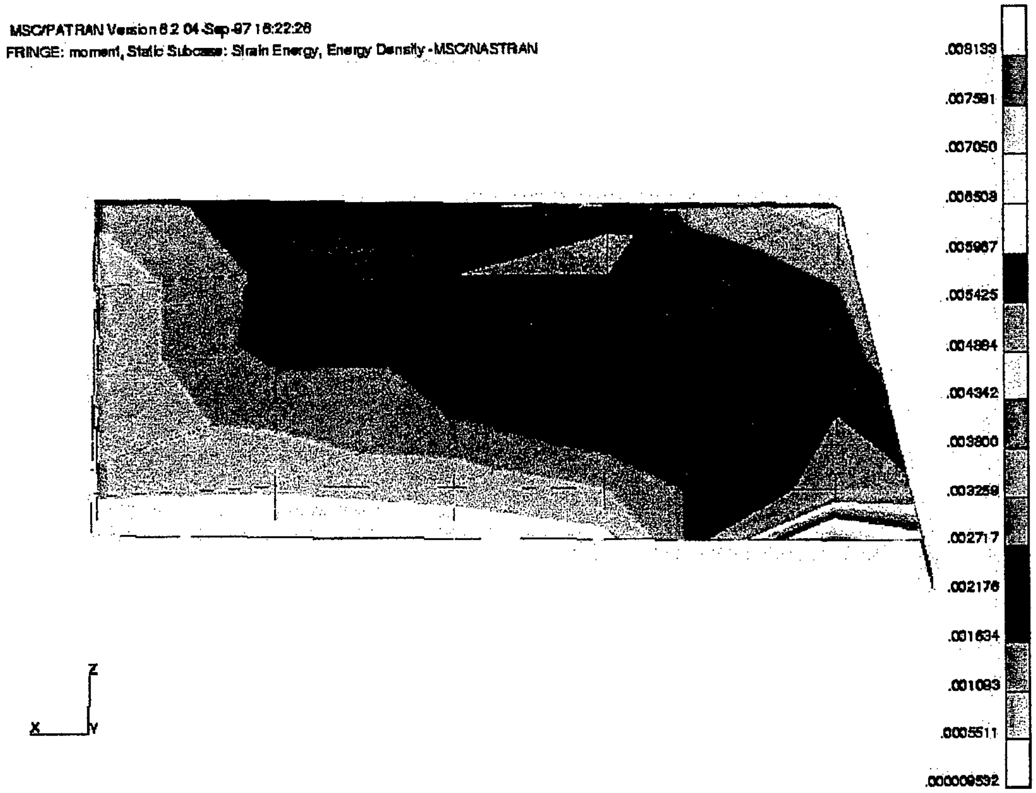

Figure 23: BAY_MOD 4 Strain Energy Density Distribution

2. BAY_MOD Selection

To create the combination models of the tailcone, one of the two BAY_MOD models had to be selected. Because weight is an issue, both BAY_MODs were analyzed to determine which one provided the most increase in torsional stiffness per pound added weight. Table 3 presents the results of this analysis. The increase in torsional stiffness is defined as the normalized percent increase over the BASE_RED model results. The weight is defined as the added weight due to the modifications in pounds. The stiffness to

weight ratio is defined as the ratio of increase in percent stiffness to a unit of weight. From table 3, BAY_MOD 4 is the best choice.

Model	Torsion Stiffness (%)	Weight (lb)	Ratio (%/lb)
BAY_MOD 1	5.5	1.02	5.43
BAY_MOD 4	6.4	0.76	8.41

Table 3: Comparison of BAY_MODs

3. Combination Model Results

Table 4 presents the results of analysis of the two combination models to the baselines. The stiffness of each model in torsion, lateral bending and vertical bending is presented for comparison. Table 5 presents the same data as the previous table normalized to the BASE_RED model results.

Model	Torsion (N-m)/degree	Horizontal Bending (N/m)	Vertical Bending (N/m)
BASE_RED	25,822	2,634,559	1,905,910
BASE _KEV	19,706	2,579,720	1,840,053
ADD_MOD	29,007	2,770,260	1,988,982
KADD_MOD	24,258	2,731,757	1,954,323

Table 4: Combination Model Stiffnesses in SI Units

Model	Torsion	Horizontal Bending	Vertical Bending
BASE_RED	1.000	1.000	1.000
BASE_KEV	0.763	0.979	0.965
ADD_MOD	1.123	1.052	1.044
KADD_MOD	0.939	1.037	1.025

Table 5: Combination Model Stiffnesses Normalized to BASE_RED Results

The BASE_KEV model simulates the prototype aircraft except that it replaces the graphite on the OML with RAM to enable the design to meet radar signature requirements. From table 5, the BASE_KEV model has almost a 24 percent decrease in torsional stiffness as compared to the BASE_RED model. This is why graphite had to be added to the prototype.

The ADD_MOD model increases the torsional stiffness of the baseline by over 12 percent. When RAM is applied to the modified model (KADD_MOD), the torsional stiffness is reduced by only six percent from the BASE_RED model. This is an increase of almost 18 percent over the BASE_KEV model. In addition, the KADD_MOD model bending stiffnesses exceed the BASE_RED model results.

B. T-TAIL RESULTS

1. Horizontal Stabilizer Results

Table 6 shows the results of the analysis on the horizontal stabilizer modification to its baseline. Only the vertical bending stiffness is analyzed. The bending stiffness is defined as the applied force per unit of z-displacement of the load application node. Table 7 presents the same data as the previous table normalized to the STAB_RED model results.

Model	Vertical Bending (N/m)
STAB_RED	66,160
STAB_MOD	117,421

Table 6: STAB Model Vertical Stiffness in SI Units

Model	Vertical Bending
STAB_RED	1.000
STAB_MOD	1.775

Table 7: STAB Model Stiffness Normalized to STAB_RED Results

Table 7 shows a 77 percent increase in the vertical bending stiffness. In addition, by removing the fold-fitting hinge, this modification reduces the gross weight from its baseline by 2.92 pounds. The center of gravity shifts forward by 0.938 inches.

2. Vertical Stabilizer Results

Table 8 presents the results of analysis of the vertical stabilizer modification to its baseline. The stiffness of each model in torsion, lateral bending and vertical bending is presented for comparison. The torsional stiffness is defined as the applied moment per degree of x-rotation of the load application node. The bending stiffness is defined as the applied force per unit of z-displacement of the load application node. Table 9 presents the same data as the previous table normalized to the VFIN_RED model results.

Model	Torsion (N-m)/degree	Horizontal Bending (N/m)	Vertical Bending (N/m)
VFIN_RED	3,447	6,655	30,177
VFIN_MOD	2,271	5,489	25,631

Table 8: VFIN Model Stiffnesses in SI Units

Model	Torsion	Horizontal Bending	Vertical Bending
VFIN_RED	1.000	1.000	1.000
VFIN_MOD	0.659	0.825	0.849

Table 9: VFIN Model Stiffnesses Normalized to VFIN_RED Results

As expected, the VFIN_MOD model is not as stiff as the original VFIN_RED model. A majority of this significant reduction in the stiffnesses can be attributed to the removal of a spar. However, an unknown percentage of the stiffness reduction is caused by the differences between the VFIN_RED and VFIN_MOD models' geometries and material properties. Further modifications that must be done to isolate the reduction in stiffness due to the spar removal are discussed in the Recommendations section. It is hoped that the rigid connection of the horizontal stabilizer to the shroud through the vertical stabilizer will recover the reduction in stiffness caused by this modification.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

One goal of this thesis was to combine the proposed modifications in order to allow the replacement of the graphite on the OML of the tailcone with RAM and achieve the stiffness of the prototype. The BASE_RED model was considered the goal for torsional stiffness and horizontal and vertical bending stiffnesses.

The modifications analyzed here did produce stiffness increases using the BASE_RED OML materials. While the modifications did increase both horizontal and vertical bending stiffnesses, torsional stiffness did not meet the BASE_RED results when using radar cross section compliant materials. Additional modifications are necessary if the remaining six percent of torsional stiffness is to be recovered. These modifications may necessitate fundamental changes to the aircraft OML or T-tail design.

The modifications to the TLGB increased selected stiffnesses with only a small weight increase that is easily offset by the modifications to the T-tail section. In addition, the Comanche Program Management Office (PMO-Comanche) is conducting a trade study on the mounting of the tail landing gear. If a new design is selected, incorporation of the BAY_MOD 4 modification should be considered.

The second goal of this thesis was to design and analyze proposed structural modifications to the Comanche's horizontal and vertical stabilizers that would incorporate the proposed tail-fold design changes. The STAB_MOD modification greatly increased the vertical bending stiffness of the horizontal stabilizer and reduced total weight.

The VFIN modification showed a significant loss in selected stiffnesses. It is hoped that when new fittings are designed, the rigid connection of the horizontal stabilizer to the shroud through the vertical stabilizer will recover the reduction in stiffness and the proposed modification can be incorporated into future modifications

B. RECOMMENDATIONS

1. VFIN_MOD Model Baseline

As stated earlier, differences between the VFIN_RED and VFIN_MOD models' geometries and material properties make it impossible to determine the actual reduction in stiffness caused by the removal of the spar. A "baseline" model of the VFIN_MOD, utilizing the same geometry and material properties, must be created containing the third spar. Comparison of this model to the VFIN_MOD would isolate the reduction in stiffness due to the spar removal.

2. VFIN_MOD Model Optimization

Due to time constraints, VFIN_MOD did not go through an optimization process to reduce weight and distribute strain energy densities. Continued analysis of the model should be conducted to fully utilize the many different material properties already contained in the tail section database.

3. Vertical Stabilizer Fittings

Now that the VFIN_MOD model exists, detailed drawings of the proposed root and attach fittings should be requested from the Boeing engineers. With these drawings, the fittings could be modeled in PATRAN and incorporated into the VFIN_MOD model. Analysis of the effects on selected stiffnesses could then show if the rigid connection of the spars by the fittings could offset the reduction in stiffness caused by the removal of one spar.

4. Dynamic Analysis of all Proposed Modifications

All work up to this point has been an analysis of static responses. The changes in natural frequencies of the modified areas could not be assessed. Helicopters are very dynamic systems, and it is the dynamic response of the aircraft that is of greatest concern. A dynamic analysis of all the proposed modifications should be conducted to gain insight on the dynamic response of the aircraft to the proposed modifications.

APPENDIX A: MODIFICATIONS LISTING

TAIL LANDING GEAR BAY MODIFICATIONS (BAY_MOD 1)								
RIGHT SIDE								
ELEMENTS REMOVED								
WEDGE						MAT	PROP	
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	X	Y	Z
QUAD4	4215802	15802	15808	15925	15924	1.4215802	psh.4215802	
TRIA3	3215925	15925	15808	15926		1.4215802	psh.4215802	
BAR2	1115802	15802	15924			1.1114827	pbr.1114827	
BAR2	1315802	15802	15808			1.1315802	pbr.1315802	
BAR2	1315808	15808	15926			1.1315802	pbr.1315802	
BAR2	1315925	15925	15924			1.1315926	pbr.1315926	
BAR2	1315926	15926	15925			1.1315926	pbr.1315926	
NODE	15808					15860.5	256.117	2867.78
LONGERON END						MAT	PROP	
TRIA3	3315642	15642	15802	15648		2.43148271	psh.4314827	
TRIA3	3315802	15802	15924	15934		2.43148271	psh.4314827	
TRIA3	3315934	15934	15648	15802		2.43148271	psh.4314827	
BAR2	1115642	15642	15806			1.1114827	pbr.1114827	
NODE	15802					15806	256.117	2792
Fwd TLGB Blkhd						MAT	PROP	
QUAD4	4114826	14826	14846	14847	14827	2.41150071	psh.4115007	
QUAD4	4114827	14827	14847	14848	14828	2.41150071	psh.4115007	
QUAD4	4114846	14846	14914	14916	14847	2.41150071	psh.4115007	
QUAD4	4114847	14847	14916	14917	14848	2.41150071	psh.4115007	
NODE	14847					14889.2	116.1785	2978.2
NODES MOVED								
TLGB Ceiling							MOVED	
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	X	Y	Z
NODE	14916					14938.6	117.669	3162.02
NODE	15111					15140.5	135.325	3162.01
NODE	15225					15244.4	152.367	3160
NODE	15421					15444.4	189.285	3160
NODE	15636					15680	232.825	3160
NODE	15928					15915	256.116	3160
NODE	15925	(RTLGBB)				15915	256.116	2863.1699
NODE	15926					15915	256.116	2943.5601
NODE	15927					15915	256.116	3051.78
NODES ADDED								
SHEAR WALL								
NODE	93057	(TLGBB)				14858.3589	115.055	2863.1699
NODE	93058					14879.9126	115.775	2943.5601
NODE	93059					14908.9351	116.75	3051.78
NODE	93060	(SW)				14938.6	117.669	2863.1699
NODE	93061					14938.6	117.669	2943.5601
NODE	93062					14938.6	117.669	3051.78
NODE	93063					15140.6	135.325	2863.1699
NODE	93064					15140.6	135.325	2943.5601
NODE	93065					15140.6	135.325	3051.78
NODE	93066					15244.4	152.367	2863.1699
NODE	93067					15244.4	152.367	2943.5601
NODE	93068					15244.4	152.367	3051.78
NODE	93069					15444.4	189.285	2863.1699
NODE	93070					15444.4	189.285	2943.5601
NODE	93071					15444.4	189.285	3051.78
NODE	93072					15680	232.825	2863.1699
NODE	93073					15680	232.825	2943.5601
NODE	93074					15680	232.825	3051.78

TAIL LANDING GEAR BAY MODIFICATIONS (BAY_MOD 1) (cont.)							
RIGHT SIDE (cont.)							
ELEMENTS ADDED							
LONGERON END							
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP
QUAD4	9090934	15624	15924	15934	15648	2.43148271	psh.4314827
BAR2	9090935	15624	15924			1.1114827	pbr.1114827
TLGBB						MAT	PROP
QUAD4	9090938	14827	93057	14848	14828	2.41150071	psh.4115007
QUAD4	9090939	14826	14846	93057	14827	2.41150071	psh.4115007
TRIA3	9090940	93057	93058	14848		2.41150071	psh.4115007
TRIA3	9090941	93058	93059	14848		2.41150071	psh.4115007
QUAD4	9090942	93059	14916	14917	14848	2.41150071	psh.4115007
QUAD4	9090943	14846	14914	14916	93059	2.41150071	psh.4115007
TRIA3	9090944	93057	14846	93058		2.41150071	psh.4115007
TRIA3	9090945	93058	14846	93059		2.41150071	psh.4115007
SHEAR WALL						MAT	PROP
QUAD4	9090946	14827	14945	93060	93057	2.43148271	psh.4314827
QUAD4	9090947	93057	93060	93061	93058	2.43148271	psh.4314827
QUAD4	9090948	93058	93061	93062	93059	2.43148271	psh.4314827
TRIA3	9090949	93059	93062	14916		2.43148271	psh.4314827
QUAD4	9090950	14945	15122	93063	93060	2.43148271	psh.4314827
QUAD4	9090951	93060	93063	93064	93061	2.43148271	psh.4314827
QUAD4	9090952	93061	93064	93065	93062	2.43148271	psh.4314827
QUAD4	9090953	93062	93065	15111	14916	2.43148271	psh.4314827
QUAD4	9090954	15122	15111	93066	93063	2.43148271	psh.4314827
QUAD4	9090955	93063	93066	93067	93064	2.43148271	psh.4314827
QUAD4	9090956	93064	93067	93068	93065	2.43148271	psh.4314827
QUAD4	9090957	93065	93068	15225	15111	2.43148271	psh.4314827
QUAD4	9090958	15224	15423	93069	93066	2.43148271	psh.4314827
QUAD4	9090959	93066	93069	93070	93067	2.43148271	psh.4314827
QUAD4	9090960	93067	93070	93071	93068	2.43148271	psh.4314827
QUAD4	9090961	93068	93071	15421	15225	2.43148271	psh.4314827
QUAD4	9090962	15423	15642	93072	93069	2.43148271	psh.4314827
QUAD4	9090963	93069	93072	93073	93070	2.43148271	psh.4314827
QUAD4	9090964	93070	93073	93074	93071	2.43148271	psh.4314827
QUAD4	9090965	93071	93074	15636	15421	2.43148271	psh.4314827
QUAD4	9090966	15642	15924	15925	93072	2.43148271	psh.4314827
QUAD4	9090967	93072	15925	15926	93073	2.43148271	psh.4314827
QUAD4	9090968	93073	15926	15927	93074	2.43148271	psh.4314827
QUAD4	9090969	93074	15927	15928	15636	2.43148271	psh.4314827

TAIL LANDING GEAR BAY MODIFICATIONS (BAY_MOD 1) (cont.)								
LEFT SIDE								
ELEMENTS REMOVED								
WEDGE						MAT	PROP	
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	X	Y	Z
QUAD4	4215909	15909	15908	15801	15807	1.4215802	psh.4215802	
TRIA3	3215910	15910	15909	15807		1.4215802	psh.4215802	
BAR2	1115801	15801	15908			1.1114827	pbr.1114827	
BAR2	1315801	15801	15807			1.1315802	pbr.1315802	
BAR2	1315807	15807	15910			1.1315802	pbr.1315802	
BAR2	1315909	15908	15909			1.1315926	pbr.1315926	
BAR2	1315910	15910	15909			1.1315926	pbr.1315926	
NODE	15807					15860.5	-135.69501	2870.5701
LONGERON END						MAT	PROP	
TRIA3	3315619	15619	15906	15801		2.43148271	psh.4314827	
TRIA3	3315801	15801	15623	15619		2.43148271	psh.4314827	
TRIA3	3315908	15908	15801	15906		2.43148271	psh.4314827	
BAR2	1115623	15623	15801			1.1114827	pbr.1114827	
NODE	15801					15806	-135.69501	2792
TLGBB						MAT	PROP	
QUAD4	4114822	14822	14842	14843	14823	2.41150071	psh.4115007	
QUAD4	4114823	14823	14843	14844	14824	2.41150071	psh.4115007	
QUAD4	4114842	14842	14909	14910	14843	2.41150071	psh.4115007	
QUAD4	4114843	14843	14910	14912	14844	2.41150071	psh.4115007	
NODE	14843					14889.2	-115.0955	2978.2
NODES MOVED								
TLGBC							MOVED	
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	X	Y	Z
NODE	14910					14938.6	-115.759	3162.02
NODE	15106					15140.5	-122.953	3162.01
NODE	15216					15244.4	-122.109	3160
NODE	15412					15444.4	-126.262	3160
NODE	15621					15680	-131.155	3160
NODE	15909	(RTLGBB)				15915	-138.978	2863.1699
NODE	15910					15915	-138.978	2949.1399
NODE	15911					15915	-138.978	3054.6899
NODE	15912					15915	-138.978	3160.25
NODES ADDED								
NODE	93075	(TLGBB)				14858.3589	-114.75	2863.1699
NODE	93076					14881.4088	-115	2949.1399
NODE	93077					14909.7155	-115.4	3054.6889
NODE	93078	(SW)				14938.6	-115.759	2863.1699
NODE	93079					14938.6	-115.759	2949.1399
NODE	93080					14938.6	-115.759	3054.6889
NODE	93081					15140.6	-122.953	2863.1699
NODE	93082					15140.6	-122.953	2949.1399
NODE	93083					15140.6	-122.953	3054.6889
NODE	93084					15244.4	-122.109	2863.1699
NODE	93085					15244.4	-122.109	2949.1399
NODE	93086					15244.4	-122.109	3054.6889
NODE	93087					15444.4	-126.262	2863.1699
NODE	93088					15444.4	-126.262	2949.1399
NODE	93089					15444.4	-126.262	3054.6889
NODE	93090					15680	-131.155	2863.1699
NODE	93091					15680	-131.155	2949.1399
NODE	93092					15680	-131.155	3054.6889

TAIL LANDING GEAR BAY MODIFICATIONS (BAY_MOD 1) (cont.)							
LEFT SIDE (cont.)							
ELEMENTS ADDED							
LONGERON END							
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP
QUAD4	9090936	15619	15906	15908	15623	2.43148271	psh.4314827
BAR2	9090937	15623	15908			1.1114827	pbr.1114827
TLGBB						MAT	PROP
TRIA3	9090970	14822	93075	14823		2.41150071	psh.4115007
TRIA3	9090971	14823	93075	14824		2.41150071	psh.4115007
TRIA3	9090972	14822	14842	93075		2.41150071	psh.4115007
TRIA3	9090973	93075	14842	93076		2.41150071	psh.4115007
TRIA3	9090974	14824	93075	14844		2.41150071	psh.4115007
TRIA3	9090975	93075	93076	14844		2.41150071	psh.4115007
QUAD4	9090976	93077	14910	14912	14844	2.41150071	psh.4115007
QUAD4	9090977	14842	14909	14910	93077	2.41150071	psh.4115007
TRIA3	9090978	93076	93077	14844		2.41150071	psh.4115007
TRIA3	9090979	14842	93077	93076		2.41150071	psh.4115007
SHEAR WALL						MAT	PROP
QUAD4	9090980	93075	93078	14943	14823	2.43148271	psh.4314827
QUAD4	9090981	93076	93079	93078	93075	2.43148271	psh.4314827
QUAD4	9090982	93077	93080	93079	93076	2.43148271	psh.4314827
TRIA3	9090983	93077	14910	93080		2.43148271	psh.4314827
QUAD4	9090984	93078	93081	15121	14943	2.43148271	psh.4314827
QUAD4	9090985	93079	93082	93081	93078	2.43148271	psh.4314827
QUAD4	9090986	93080	93083	93082	93079	2.43148271	psh.4314827
QUAD4	9090987	14910	15106	93083	93080	2.43148271	psh.4314827
QUAD4	9090988	93081	93084	15219	15121	2.43148271	psh.4314827
QUAD4	9090989	93082	93085	93084	93081	2.43148271	psh.4314827
QUAD4	9090990	93083	93086	93085	93082	2.43148271	psh.4314827
QUAD4	9090991	15106	15216	93086	93083	2.43148271	psh.4314827
QUAD4	9090992	93084	93087	15414	15219	2.43148271	psh.4314827
QUAD4	9090993	93085	93088	93087	93084	2.43148271	psh.4314827
QUAD4	9090994	93086	93089	93088	93085	2.43148271	psh.4314827
QUAD4	9090995	15216	15412	93089	93086	2.43148271	psh.4314827
QUAD4	9090996	93087	93090	15623	15414	2.43148271	psh.4314827
QUAD4	9090997	93088	93091	93090	93087	2.43148271	psh.4314827
QUAD4	9090998	93089	93092	93091	93088	2.43148271	psh.4314827
QUAD4	9090999	15412	15621	93092	93089	2.43148271	psh.4314827
QUAD4	9091000	93090	15909	15908	15623	2.43148271	psh.4314827
QUAD4	9091001	93091	15910	15909	93090	2.43148271	psh.4314827
QUAD4	9091002	93092	15911	15910	93091	2.43148271	psh.4314827
QUAD4	9091003	15621	15912	15911	93092	2.43148271	psh.4314827

TAIL LANDING GEAR BAY MODIFICATIONS (BAY_MOD 4)								
RIGHT SIDE								
ELEMENTS REMOVED								
WEDGE								
						MAT	PROP	
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	X	Y	Z
QUAD4	4215802	15802	15808	15925	15924	1.4215802	psh.4215802	
TRIA3	3215925	15925	15808	15926		1.4215802	psh.4215802	
BAR2	1115802	15802	15924			1.1114827	pbr.1114827	
BAR2	1315802	15802	15808			1.1315802	pbr.1315802	
BAR2	1315808	15808	15926			1.1315802	pbr.1315802	
BAR2	1315925	15925	15924			1.1315926	pbr.1315926	
BAR2	1315926	15926	15925			1.1315926	pbr.1315926	
NODE	15808					15860.5	256.117	2867.78
LONGERON END						MAT	PROP	
TRIA3	3315642	15642	15802	15648		2.43148271	psh.4314827	
TRIA3	3315802	15802	15924	15934		2.43148271	psh.4314827	
TRIA3	3315934	15934	15648	15802		2.43148271	psh.4314827	
BAR2	1115642	15642	15806			1.1114827	pbr.1114827	
NODE	15802					15806	256.117	2792
ELEMENTS ADDED								
LONGERON END								
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP	
QUAD4	9090934	15624	15924	15934	15648	2.43148271	psh.4314827	
BAR2	9090935	15624	15924			1.1114827	pbr.1114827	
NODES MOVED								
LONGERON							MOVED	
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	X	Y	Z
NODE	14827					14842.6	90	2804.3899
NODE	14945					14938.6	105.21	2792
NODE	15122					15140.6	136.16	2792
NODE	15224					15244.4	152.25	2792
NODE	15423					15444.4	183.35	2792
NODE	15642					15680	219.99	2792
DIAGONAL LONGERON							MOVED	
NODE	14914					14938.6	105.21	3162.02
NODE	14847					14889.2	97.432	2978.2
NODE	15925					15915	256.116	2821.23
NODES ADDED								
DIAGONAL LONGERON								
NODE	93057					15140.6	136.16	3085.3799
NODE	93058					15244.4	152.25	3048.76
NODE	93059					15444.4	183.35001	2980.73
NODE	93060					15680	219.99001	2900.8701
ELEMENTS ADDED								
SHEAR WALL								
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP	
TRIA3	9090961	14827	14945	14847		2.43148271	psh.4314827	
TRIA3	9090962	14945	14914	14847		2.43148271	psh.4314827	
QUAD4	9090937	14945	15122	93057	14914	2.43148271	psh.4314827	
QUAD4	9090938	15122	15224	93058	93057	2.43148271	psh.4314827	
QUAD4	9090939	15224	15423	93059	93058	2.43148271	psh.4314827	
QUAD4	9090940	15423	15642	93060	93059	2.43148271	psh.4314827	
QUAD4	9090941	15642	15924	15925	93060	2.43148271	psh.4314827	
DIAGONAL LONGERON								
QUAD4	9090944	93057	15130	14918	14914	2.43148271	psh.4314827	
QUAD4	9090945	93058	15234	15130	93057	2.43148271	psh.4314827	
QUAD4	9090946	93059	15431	15234	93058	2.43148271	psh.4314827	
QUAD4	9090947	93060	15650	15431	93059	2.43148271	psh.4314827	
QUAD4	9090948	15925	15935	15650	93060	2.43148271	psh.4314827	

TAIL LANDING GEAR BAY MODIFICATIONS (BAY_MOD 4) (Cont.)								
LEFT SIDE								
ELEMENTS REMOVED								
WEDGE						MAT	PROP	
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	X	Y	Z
QUAD4	4215909	15909	15908	15801	15807	1.4215802	psh.4215802	
TRIA3	3215910	15910	15909	15807		1.4215802	psh.4215802	
BAR2	1115801	15801	15908			1.1114827	pbr.1114827	
BAR2	1315801	15801	15807			1.1315802	pbr.1315802	
BAR2	1315807	15807	15910			1.1315802	pbr.1315802	
BAR2	1315909	15908	15909			1.1315926	pbr.1315926	
BAR2	1315910	15910	15909			1.1315926	pbr.1315926	
NODE	15807					15860.5	-135.69501	2870.5701
LONGERON END						MAT	PROP	
TRIA3	3315619	15619	15906	15801		2.43148271	psh.4314827	
TRIA3	3315801	15801	15623	15619		2.43148271	psh.4314827	
TRIA3	3315908	15908	15801	15906		2.43148271	psh.4314827	
BAR2	1115623	15623	15801			1.1114827	pbr.1114827	
NODE	15801					15806	-135.69501	2792
ELEMENTS ADDED								
LONGERON END								
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP	
QUAD4	9090942	15619	15906	15908	15623	2.43148271	psh.4314827	
BAR2	9090943	15623	15908			1.1114827	pbr.1114827	
NODES MOVED								
LONGERON							MOVED	
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	X	Y	Z
NODE	14943					14938.6	-116.75	2792
NODE	15121					15140.6	-121.34	2792
NODE	15219					15244.4	-123.7	2792
NODE	15414					15444.4	-128.26	2792
NODE	15623					15680	-133.63	2792
DIAGONAL LONGERON								
NODE	15909					15915	-138.978	2863.1699
NODES ADDED								
DIAGONAL LONGERON								
NODE	93062					14938.6	-116.75	2907.8601
NODE	93063					15140.6	-121.35	2908.73
NODE	93064					15244.4	-123.7	2908.73
NODE	93065					15444.4	-128.26	2908.73
NODE	93066					15680	-133.63	2897.6101
ELEMENTS ADDED								
SHEAR WALL								
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP	
TRIA3	9090949	14823	93062	14943		2.43148271	psh.4314827	
QUAD4	9090950	14943	93062	93063	15121	2.43148271	psh.4314827	
QUAD4	9090951	15121	93063	93064	15219	2.43148271	psh.4314827	
QUAD4	9090952	15219	93064	93065	15414	2.43148271	psh.4314827	
QUAD4	9090953	15414	93065	93066	15623	2.43148271	psh.4314827	
QUAD4	9090954	15623	93066	15909	15908	2.43148271	psh.4314827	
DIAGONAL LONGERON								
QUAD4	9090955	14823	14822	14940	93062	2.43148271	psh.4314827	
QUAD4	9090956	93062	14940	15116	93063	2.43148271	psh.4314827	
QUAD4	9090957	93063	15116	15212	93064	2.43148271	psh.4314827	
QUAD4	9090958	93064	15212	15408	93065	2.43148271	psh.4314827	
QUAD4	9090959	93065	15408	15617	93066	2.43148271	psh.4314827	
QUAD5	9090960	93066	15617	15905	15909	2.43148271	psh.4314827	

HORIZONTAL STABILATOR MODIFICATIONS (STAB_MOD)							
ELEMENTS REMOVED							
HINGES							
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP
QUAD4	4144105	44105	44104	44203	44205	1.4144105	psh.4144105
QUAD4	4144108	44108	44207	44201	44101	1.4144105	psh.4144105
QUAD4	4144305	44305	44206	44204	44304	1.4144105	psh.4144105
QUAD4	4144308	44308	44301	44202	44208	1.4144105	psh.4144105
BULKHEAD							
QUAD4	5244101	44101	44108	44107	44102	1.5241001	psr.5241001
QUAD4	5244102	44102	44107	44106	44103	1.5241001	psr.5241001
QUAD4	5244103	44103	44106	44105	44104	1.5241001	psr.5241001
BAR2	1144101	44101	44102			1.1141001	pbr.1141001
BAR2	1144102	44102	44103			1.1141001	pbr.1141001
BAR2	1144103	44103	44105			1.1141001	pbr.1141001
BAR2	1144105	44105	44106			1.1141001	pbr.1141001
BAR2	1144106	44106	44107			1.1141001	pbr.1141001
BAR2	1144107	44107	44108			1.1141001	pbr.1141001
BAR2	1344104	44104	44105			1.1141001	pbr.1141001
BAR2	1344108	44108	44101			1.1141001	pbr.1141001
BAR2	2344106	44106	44103			1.2341006	cr.m2341006
BAR2	2344107	44107	44102			1.2341006	cr.m2341006
ELEMENTS ADDED							
CORE							
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP
BAR2	6348165	44108	44308			1.4144105	pbr.1244001
BAR2	6348166	44101	44301			1.4144105	pbr.1244001
HEX8	6348167	44154	44151	44152	44153	9.6331054	psd.6331054
		44354	44351	44352	44353		
HEX8	6348168	44153	44152	44101	44108	9.6331054	psd.6331054
		44353	44352	44301	44308		
QUAD4	6341869	44108	44308	44301	44101	1.4144105	psh.4144001
BAR2	6341870	44105	44305			1.4144105	pbr.1244001
BAR2	6341871	44104	44304			1.4144105	pbr.1244001
HEX8	6341872	44164	44163	44162	44161	9.6331054	psd.6331054
		44364	44363	44362	44361		
HEX8	6348173	44105	44164	44161	44104	9.6331054	psd.6331054
		44305	44364	44361	44304		
QUAD4	6348174	44104	44304	44305	44105	1.4144105	psh.4144001
OUTER SKIN							
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP
QUAD4	6348175	44164	44163	44363	44364	2.44410011	psh.4441001
QUAD4	6348176	44105	44164	44364	44305	2.44410011	psh.4441001
QUAD4	6348177	44153	44108	44308	44353	2.44410011	psh.4441001
QUAD4	6348178	44154	44153	44353	44354	2.44410011	psh.4441001
QUAD4	6348179	44151	44154	44354	44351	2.44410011	psh.4441001
QUAD4	6348180	44163	44162	44362	44363	2.44410011	psh.4441001
QUAD4	6348181	44162	44161	44361	44362	2.44410011	psh.4441001
QUAD4	6348182	44161	44104	44304	44361	2.44410011	psh.4441001
QUAD4	6348183	44101	44152	44352	44301	2.44410011	psh.4441001
QUAD4	6348184	44152	44151	44351	44352	2.44410011	psh.4441001
QUAD4	6348185	44106	44105	44305	44306	2.43411061	psh.4341106
QUAD4	6348186	44107	44106	44306	44307	2.43411061	psh.4341106
QUAD4	6348187	44108	44107	44307	44308	2.43411061	psh.4341106
QUAD4	6348188	44104	44103	44303	44304	2.43410011	psh.4341001
QUAD4	6348189	44103	44102	44302	44303	2.43410011	psh.4341001
QUAD4	6348190	44102	44101	44301	44302	2.43410011	psh.4341001

VERTICAL STABILIZER MODIFICATIONS (VFIN_MOD)							
ELEMENTS REMOVED							
ATTACH FITTING							
ELEMENT	ID	NODE 1	NODE 2	NODE 3	NODE 4	MAT	PROP
QUAD4	4332338	32336	32338	32394	32395	1.4144105	psh.4332338
QUAD4	4332391	32374	32340	32391	32392	1.4144105	psh.4332338
TRIA3	3144401	32391	44401	44408		1.4144105	psh.9144401
TRIA3	3144404	44404	44405	44410		1.4144105	psh.3144401
TRIA3	3145001	32394	45001	45008		1.4144105	psh.8144401
TRIA3	3332338	32338	32393	32394		1.4144105	psh.4332338
TRIA3	3332340	32340	32390	32391		1.4144105	psh.4332338
TRIA3	3332389	32384	32389	32397		1.4144105	psh.3332389
BAR2	2335203	32397	44410			1.2335203	pbr.2335203
ROOT FITTING							
QUAD4	4221205	21205	21305	21326	21226	1.4221306	psh.4224625
QUAD4	4221605	21105	21205	21226	21126	1.4221306	psh.4224625
QUAD4	4224625	24625	21105	21126	24621	1.4221306	psh.4224625
QUAD4	4424631	24631	24632	21107	24607	1.4221306	psh.4224625
QUAD4	4424632	24632	24633	21207	21107	1.4221306	psh.4224625
QUAD4	4424633	24633	24634	21307	21207	1.4221306	psh.4224625
QUAD4	4332619	32619	32638	32639	32621	1.4144105	psh.4332525
QUAD4	4332633	32633	32644	32645	32634	1.4144105	psh.4332633
QUAD4	4332640	32640	32622	32623	32641	1.4144105	psh.4332525
QUAD4	4332642	32642	32630	32632	32643	1.4144105	psh.4332642
TRIA3	3121305	21305	21326	21306		1.4144105	psh.4121306
TRIA3	3121306	21306	21326	21327		1.4144105	psh.4121306
TRIA3	3121307	21307	21306	24634		1.4144105	psh.4121306
TRIA3	3124605	24605	24621	24606		1.4144105	psh.4121307
TRIA3	3124606	24606	24621	24620		1.4144105	psh.4121308
TRIA3	3124607	24607	24606	24631		1.4144105	psh.4121307
TRIA3	3124625	24625	24621	24605		1.4144105	psh.4121307
TRIA3	3124631	24631	24606	24620		1.4144105	psh.4121307
TRIA3	3124634	24634	21306	21327		1.4144105	psh.4121306
TRIA3	3332626	32623	32620	32641		1.4144105	psh.4332525
TRIA3	3332634	32632	32631	32643		1.4144105	psh.4332642
TRIA3	3332639	32639	32620	32621		1.4144105	psh.4332525
TRIA3	3332645	32645	32631	32634		1.4144105	psh.4332633
BAR2	2335203	32397	44410			1.2335203	pbr.2335203
BAR2	2335203	32397	44410			1.2335203	pbr.2335203
BAR2	1121126	21126	21226			1.4221306	pbr.1124621
BAR2	1121226	21226	21326			1.4221306	pbr.1124621
BAR2	1124621	24621	21126			1.4221306	pbr.1124621
BAR2	1124631	24631	24632			1.4221306	pbr.1124621
BAR2	1124632	24632	24633			1.4221306	pbr.1124621
BAR2	1124633	24633	24634			1.4221306	pbr.1124621
BAR2	1221326	21326	21327			1.4221306	pbr.1124621
BAR2	1224620	24620	24612			1.4144105	pbr.1324620
BAR2	1321306	21306	21326			1.4144105	pbr.1324620
BAR2	1321326	21326	21305			1.4144105	pbr.1321360
BAR2	1321327	21327	21306			1.4144105	pbr.1321360
BAR2	1321328	21327	21307			1.4144105	pbr.1321360
BAR2	1324607	24607	24620			1.4144105	pbr.1321360
BAR2	1324620	24620	24606			1.4144105	pbr.1324620
BAR2	1324621	24621	24606			1.4144105	pbr.1324620
BAR2	1324625	24625	24621			1.4144105	pbr.1324620
BAR2	1421305	21305	21306			1.4144105	pbr.1324620
BAR2	1421306	21306	21307			1.4144105	pbr.1421305
BAR2	1424605	24605	24606			1.4144105	pbr.1421305
BAR2	1424606	24606	24607			1.4144105	pbr.1424605
BAR2	1424625	24625	24605			1.4144105	pbr.1424605
						1.4144105	pbr.1424605

VERTICAL STABILIZER MODIFICATIONS (VFIN_MOD) (Cont.)				
ELEMENTS ADDED				
SPAR WEBS	9339005:9339132			
ELEMENT	ID	LOCATION	MAT	PROP
QUAD4	9339005:9339064	Fwd	1.4130262	psh.4130262
QUAD4	9339065:9339068	Fwd Btm	1.4130964	psh.4130964
QUAD4	9339069:9339128	Aft	1.4130262	psh.4130262
QUAD4	9339129:9339132	Aft Btm	1.4130964	psh.4130964
SPAR ENDCAPS	9339133:9339260			
QUAD4	9339133:9339134	Fwd Lf Top	1.4144105	psh.4239999
QUAD4	9339135:9339162	Fwd Lf	1.4230622	psh.4230622
QUAD4	9339163:9339164	Fwd Lf Btm	1.4144105	psh.4332525
QUAD4	9339165:9339166	Aft Lf	1.4230622	psh.4230622
QUAD4	9339167	Aft Lf Top	1.47144105	psh.4239999
QUAD4	9339168:9339195	Aft Lf	1.4230622	psh.4230622
QUAD4	9339196	Aft Lf Btm	1.4144105	psh.4332525
QUAD4	9339197:9339198	Fwd Rt Top	1.47144105	psh.4239999
QUAD4	9339199:9339226	Fwd Rt	1.4230622	psh.4230622
QUAD4	9339227:9339228	Fwd Rt Btm	1.4144105	psh.4332525
QUAD4	9339229	Aft Rt	1.4230622	psh.4230622
QUAD4	9339230	Aft Rt Top	1.47144105	psh.4239999
QUAD4	9339231:9339259	Aft Rt	1.4230622	psh.4230622
QUAD4	9339260	Aft Rt Btm	1.4144105	psh.4332525
FIN SKIN	9339261:9339280			
QUAD4	9339261:9339294	Fwd Lf End Cap Cover	1.4430001	psh.4430001
QUAD4	9339295:9339330	Aft Lf End Cap Cover	1.4430001	psh.4430001
QUAD4	9339331:9339366	Fwd Rt End Cap Cover	1.4430001	psh.4430001
QUAD4	9339367:9339400	Aft Rt End Cap Cover	1.4430001	psh.4430001
QUAD4	9339401:9339604	Front Shroud Cover	1.4430001	psh.4430001
QUAD4	9339605:9339782	Rear Shroud Cover	1.4430001	psh.4430001
QUAD4	9339783:9340530	Left Inner/Outer Skin	1.4430001	psh.4430001
QUAD4	9340531:9341278	Right Inner/Outer Skin	1.4430001	psh.4430001
QUAD4	9341279:9341280	Rear Shroud Top Cover	1.4430001	psh.4430001
TOP IML	9341281:9341330			
QUAD4	9341281:9341296	Fwd Lf/Rt IML	1.42300880	psh.4230088
QUAD4	9341297:9341316	Mid Lf/Rt IML	1.42300980	psh.4230098
QUAD4	9341317:9341328	Aft Lf/Rt IML	1.42300590	psh.4230059
QUAD4	9341329:9341330	Front IML	1.42300590	psh.4230059
TOP VF	9341331:9341402			
QUAD4	9341331:9341390	Top of VF	1.43322950	psh.4332295
QUAD4	9341391:9341402	Reinforced above spars	1.4144105	psh.4239999
BTM IML	9341403:9341422			
QUAD4	9341403:9341422	Btm IML	1.42306370	psh.4230637
BTM VF	9341423:9341470			
QUAD4	9341423:9341462	Bottom of VF	1.43325130	psh.4332513
QUAD4	9341463:9341470	Reinforced below spars	1.4144105	psh.4332525
FIN CORE	9341471:9342610			
HEX8	9341471:9341650	Front Shroud	9.64300010	psd.6430001
HEX8	9341651:9341794	Rear Shroud	9.64300010	psd.6430001
HEX8	9341795:9342610	Sides	9.64300010	psd.6430001

APPENDIX B: WEIGHTS AND CENTER OF GRAVITY CHANGES

RESULTS OF MODEL WEIGHTS AND COG CHANGES (BAY_MODS)							
Model	Group	x-CG	Mass	x-Moment		delta weight	delta CG
		(mm)	(kg)	(kg-mm)		(lb)	(in aft)
Base_Red	Mod1_wt	15407.29	0.6651137	10247.5997			
Bay_Mod 1	Mod1_wt	15365.4	2.910465	44720.4589			
change			2.2453513	34472.8593		1.01847404	0.28227937
Base_Red	Mod4_wt	15522.08	0.7489501	11625.2634			
Bay_Mod 4	Mod4_wt	15331.91	2.428776	37237.775			
change			1.6798259	25612.5117		0.76195608	0.20972684

RESULTS OF MODEL WEIGHTS AND COG CHANGES (STAB_MOD)							
Model	Group	x-CG	Mass	x-Moment		delta weight	delta CG
		(mm)	(kg)	(kg-mm)		(lb)	(in fwd)
Stab_Red	removed_wt	17782.75	7.108364	126406.26			
Stab_Mod	Mod_wt	17821.98	0.6669286	11885.9882			
change			-6.4414354	114520.272		-2.92178545	0.93774381

APPENDIX C: LIST OF PATRAN DATABASE FILES

base_red.db	Baseline Model for Tailcone
base_kev.db	Baseline Geometry Model for Tailcone with Kevlar OML
bay_mod 1.db	TLGB Modification 1, Baseline materials
bay_mod 4.db	TLGB Modification 2, Baseline materials
add_mod.db	Combination Model 1, (bulk-mod, cone-mod and bay-mod 1), Baseline materials
kadd_mod.db	Combination Model 2, (bulk-mod, cone-mod and bay-mod 1), Kevlar OML
stab_red.db	Baseline Model for Horizontal Stabilizer
stab_mod.db	Horizontal Stabilizer Modification
vfin_red	Baseline Model for Vertical Stabilizer
vfin_mod	Vertical Stabilizer Modification

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4. MSC/PATRAN Installation and Operations Manual, The MacNeal-Schwendler Corporation, Los Angeles, California, 1996.

5. Tobin, Vincent M., *Analysis of Potential Structural Design Modifications for the Tail Section of the RAH-66 Comanche Helicopter*, Master's Thesis, Naval Postgraduate School, Monterey, California, September, 1997.

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